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Technical Report

RATING LIFT CRANES OPERATING ON PLATFORMS IN THE OCEAN ENVIRONMENT SAE J-1366 –

Proposed SAE Recommended Practice (Version 4.0)

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Abstract This report presents the computation procedure that is used to produce load rating charts for cranes operating on platforms in the ocean environment. A rating charge defines the load that can be safely lifted for each boom angle in the boom operating range. The platform supporting the crane may be a fixed offshore platform or a ship or barge. During the crane operating cycle, loads will be lifted from or placed on a work boat or some other small vessel. The procedures utilizes the relative motion of the supporting platform and the vessel alongside to determine dynamic load factors. The dynamic load factors are applied to the land rating to derate the crane for marine operations. The computation procedure has been implemented in a computer program that is also discussed.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in²	square inches	6.5	square centimeters	cm²
ft²	square feet	0.09	square meters	m²
yd²	square yards	0.8	square meters	m²
mi²	square miles	2.6	square kilometers	km²
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft³	cubic feet	0.03	cubic meters	m³
yd³	cubic yards	0.76	cubic meters	m³
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm²	square centimeters	0.16	square inches	in²
m²	square meters	1.2	square yards	yd²
km²	square kilometers	0.4	square miles	mi²
ha	hectares (10,000 m²)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m³	cubic meters	35	cubic feet	ft³
m³	cubic meters	1.3	cubic yards	yd³
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13 10 286.
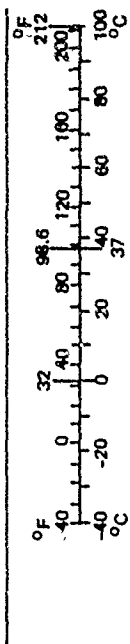
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This report presents the computation procedure that is used to produce load rating charts for cranes operating on platforms in the ocean environment. A rating charge defines the load that can be safely lifted for each boom angle in the boom operating range. The platform supporting the crane may be a fixed offshore platform or a ship or barge. During the crane operating cycle, loads will be lifted from or placed on a work boat or some other small vessel. The procedures utilizes the relative motion of the supporting platform and the vessel alongside to determine dynamic load factors. The dynamic load factors are applied to the land rating to derate the crane for marine operations. The computation procedure has been implemented in a computer program that is also discussed.

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RATING LIFT CRANES OPERATING ON PLATFORMS
IN THE OCEAN ENVIRONMENT

INTRODUCTION

This report contains the completed proposed Society of Automotive Engineers (SAE) Recommended Practice J-1366. The Recommended Practice has been developed and tested using a computer program in order to simplify understanding the rating procedure being employed and to simplify implementing the procedure in daily practice. The theory used in the procedure has been documented in publications which are listed in the reference section of the proposed document. Further documentation appears unnecessary and redundant. This report, however, presents the recommended practice, including the accompanying computer program for review and approval purposes.

An example problem section is included in this report to facilitate understanding how one might use the recommended practice. A library of crane supporting platform response amplitude operators has been included to help demonstrate what is required from the customer. These data were produced using the RELMO computer program, available from the Naval Civil Engineering Laboratory. A second program, RELMOSAE was used to extract the operators required in the SAE J-1366 procedure. An example crane is also included to help demonstrate how to prepare the crane data. This example can be enhanced in a number of ways as shown in the crane modeling guide section. Rating charts are provided for each of the platforms in the library to demonstrate how the ratings differ for various supporting platforms.

Engineers desiring to use the program on cranes of their manufacture are invited to contact the Society of Automotive Engineers. The section discussing obtaining the program shows the various options that are available. A section discussing how one runs the program is also included.

ACKNOWLEDGMENT

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SECTION I

PROPOSED RECOMMENDED PRACTICE - SAE J-1366

1. PURPOSE: The purpose of this recommended practice is to establish the design dynamic loads, the calculation procedures for rated loads, and a load-rating chart format for lift cranes operating in a variety of sea conditions.

2. SCOPE: The scope of this recommended practice is limited to a lift crane mounted on a fixed or floating platform lifting loads from a vessel alongside. The size of the vessel is assumed not to exceed that of a workboat as defined in 4.15.

3. APPLICATIONS: This recommended practice establishes a method of arriving at standard dynamic loads presumed to act on a crane operating in various specified sea conditions. The load factors are used to determine dynamic rated loads for the crane when operating in the specified sea conditions. The dynamic loads specified were arrived at by consultations between crane manufacturers, users, and Navy personnel on the interaction between environmental effects and ship motions.

3.1 Crane Manufacturers Responsibility: To calculate the static and dynamic rated capacity of the crane for the standard specified sea conditions and to publish the rating chart.

3.2 Users Responsibility: To determine sea condition existing when lift work is to be performed so that the proper rated-load column can be selected. The sea condition may be determined by consultation with on-site expert personnel such as ship captain, lift work superintendent, etc. The appropriate rating thus determined should be relayed to the crane operator and stay in effect until similarly revised.

3.3 Customers Responsibility: Provide the crane manufacturer with the required response amplitude operators for the crane supporting vessel. The heave, roll, and pitch response amplitude operators for a 135 deg incident wave shall be provided for the desired operating water depth.

The response amplitude operators are complex numbers in polar form for each wave frequency to be considered. They are expressed in terms of the modulus (feet/foot or radius/foot) and amplitude (radians). Additionally, the customer shall specify the location of the crane on the deck of the supporting vessel and the height of the deck above the water. The customer shall also provide the necessary crane parameters such as the desired boom length and number of parts of load hoist line. The customer-supplied information will be used as input for the rating program described in Appendix A. The computer program and user documentation can be obtained through the Society of Automotive Engineers.

3.4 Special Considerations Affecting Application:

3.4.1 Ballasting systems capable of reducing load-induced platform motion throughout the crane operating procedure(s) are to be considered in determination of list and trim loading on the crane (Appendix B).

3.4.2 A mooring system of anchor winches capable of adequately limiting platform response to wave action is to be considered in determination of platform motion response factors.

3.4.3 A heave-compensating device used in the load hoist system may allow an increase in the dynamic rated load. The amount of reduction should be based on the crane manufacturer's interpretation of performance test data.

3.4.4 For loads lifted from a platform on which a crane is mounted, V_D, A_D and V_{BP} in Equation 2 are assumed zero, and the picking peak dynamic load is greatly reduced. A rated load greater than the static rated load as defined in paragraph 6.3 shall not be used.

3.4.5 After the crane lifts the load, the load rating should consider boom point acceleration and load pendulation effects (see paragraph 9.0).

4. DEFINITIONS

4.1 Significant value is the average of the highest one-third of given population values. Population values may refer to wave height, roll, pitch, or yaw angles, etc. The significant value is twice the standard deviation, assuming a zero mean time history.

4.2 Sea state is an indicator relating the height of the waves to sea conditions in relative terms.

4.3 Wave instrument reading as used on the load rating chart indicates the value obtained from a wave buoy or a wave staff that relates to the sea conditions. The wave instrument reading can be analyzed to form the ratio of the average wave height to the average period $(\bar{H}/\bar{T})$.

4.4 Wave height is the vertical distance from wave crest to trough.

4.5 Surge is the single amplitude (SA) fore and aft ship motion along the longitudinal axis through the center of gravity (see Fig. 1).

4.6 Sway is the SA athwart ship motion along the transverse axis through the center of gravity (see Fig. 1).

4.7 Heave is the SA vertical ship motion along the vertical axis through the center of gravity (see Fig. 1).

4.8 Roll is the SA angular ship motion about the longitudinal axis through the center of gravity (see Fig. 1).

4.9 Pitch is the SA angular ship motion about the transverse axis through the center of gravity (see Fig. 1).

4.10 Yaw is the SA angular ship motion about the vertical axis through the center of gravity (see Fig. 1).

4.11 Offlead is the percent slope from the vertical in the vertical plane of the boom that locates the position of the load with respect to the tip of the boom.

4.12 Sidelead is the percent slope from the vertical normal to the vertical plane of the boom that locates the position of the load with respect to the tip of the boom.

4.13 Dynamic rated load (W_D) is the maximum load that can be lifted under specified dynamic conditions without exceeding allowable strength limits.

4.14 Static rated load (W_S) is 75% of the maximum load that can be lifted under normal land conditions without exceeding allowable strength limits.

4.15 A typical workboat is a vessel of 180-ft length, 40-ft beam, and 1,500-long-ton displacement.

4.16 List is the angle of inclination of ship about the longitudinal axis through the center of gravity.

4.17 Trim is the angle of inclination of ship about the transverse axis through the center of gravity.

4.18 Load hoist line velocity is the full load hoist speed at the drum based on the maximum rated load for the specified rope.

4.   (Continued)
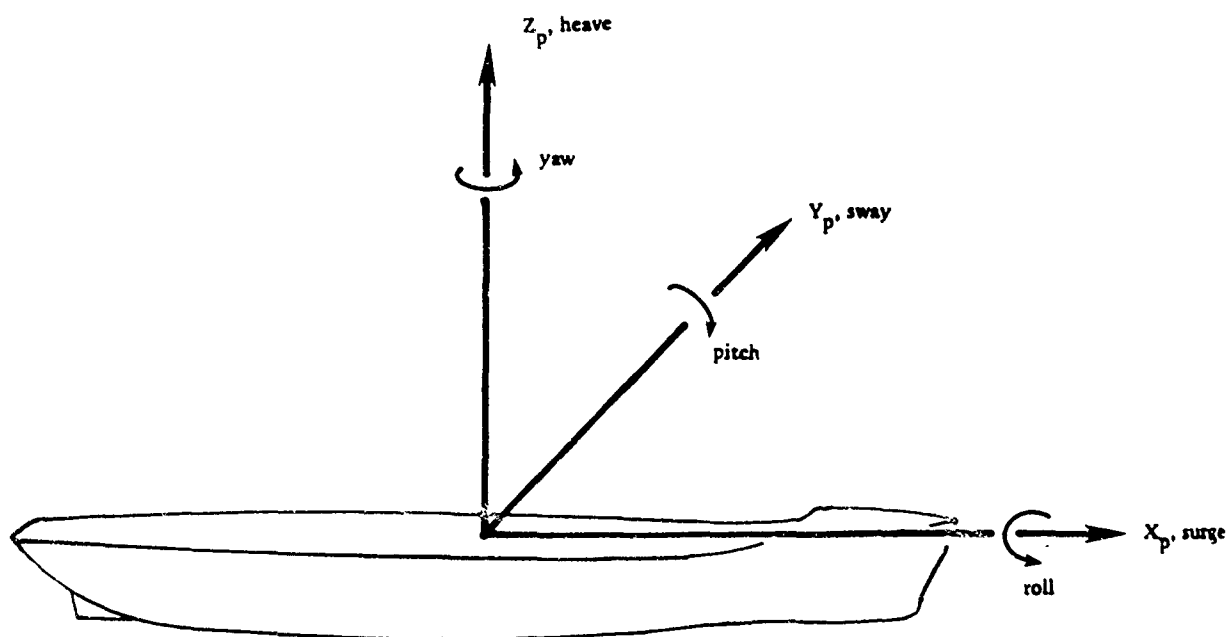
FIG. 1 - PLATFORM MOTION COORDINATE SYSTEM

5.   DYNAMIC LOAD: The dynamic load being addressed is imposed on the crane
      at the time of load liftoff from the moving deck of the vessel alongside.
      Additionally, consideration is directed to the effects of the horizontal
      displacement in the plane of the boom and normal to the plane of the boom
      caused by surge and sway of the vessel.

      After studying the motions of a workboat, it is assumed that the
      vertical motion follows wave amplitude and that horizontal motions include
      sway, surge, and yaw, but exclude drift.

      The vertical dynamic load, P (lb), that occurs when the lifted load
      W (lb) is directly under the boom tip is given by the equation:

$$P = W \left\{ 1 + \left[\frac{K}{g\,W} (V_D + V_H)^2 + \left(\frac{A_D}{g} \right)^2 \right]^{1/2} \right\} \qquad (1)$$

where: g = acceleration due to gravity (ft/sec^2)

K = vertical structural stiffness component with the load
force at appropriate offlead (lb/ft)

V_D = vertical velocity of the workboat deck at the pick point
(ft/sec)

V_H = velocity of the load hook which includes the load hoist
line velocity, parts of line, and the boom point velocity
V_{BP} (ft/sec)

A_D = acceleration of the workboat deck at the pick point
(ft/sec^2)

Since Equation 1 is a quadratic equation in terms of W, Equation 1 may be
solved for W and called W_D:

$$\frac{1}{W_D} = \frac{-B \pm \sqrt{B^2 - 4\,A\,C}}{2\,A} \qquad\qquad (2)$$

where: $A = P_{max}^2$

$$B = -2\,P_{max} - \frac{K\left(V_D + V_H\right)^2}{g}$$

$$C = 1 - \left(\frac{A_D}{g}\right)^2$$

Wave heights and periods, V_D, A_D, and V_{BP} are calculated considering
the sea spectrum, ship motion response to the spectrum sea and boom point
position. The values for V_D, A_D, and V_{BP} selected for rating purposes,
are the 90% probability of occurrence values (see Appendix A). The crane
is assumed to be in a rating position as shown in Fig. 2. Implicit in

5.   (Continued)
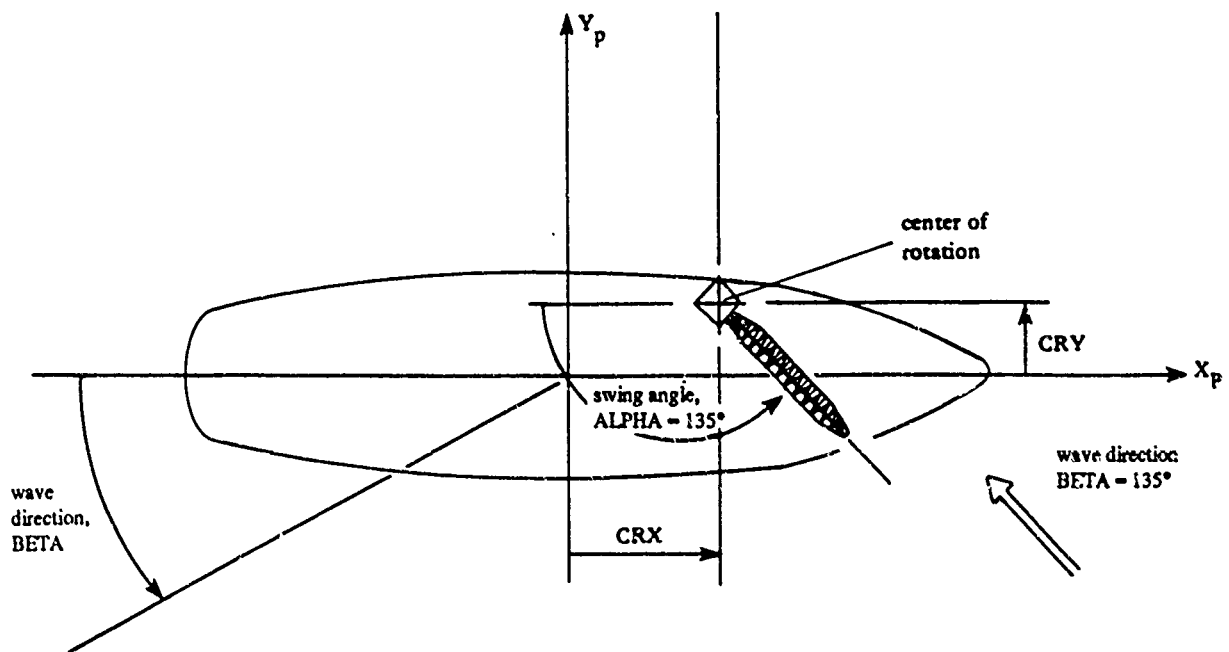
FIG. 2 - STANDARD CRANE RATING CONDITIONS: CRANE
ORIENTATION AND SEA DIRECTION

well as sidelead and offlead effects. See Table I for sidelead and
offlead values. Equation 2 is to be used to calculate a series of values
for W_D corresponding to values of $\bar{H}/\bar{T}$, such as those listed in Table II.

6.   CALCULATION PROCEDURE: The dynamic rating calculation procedure outlined
below is implemented in a computer program which is described in Appendix
A.   The calculated dynamic rated loads (W_D) will not produce a peak dynamic
load that will exceed the land rated load (P_L).

6.1 Land Rated Load: Begin the calculation procedure with a land rated load
(P_L) for each W_D that will be listed on the dynamic rating chart. The
land rated load, P_L, is determined by referencing strength margins to
standard industry test practice for land cranes, without limitations due
to the number of parts of load hoist line. This paragraph does not imply

6.1 (Continued)

that a crane test is required, however, it does imply that the crane has been properly rated for land use, that is, it would pass SAE J987 if tested.

6.1.1 Strength margins for land rated loads in all areas above the top slewing ring mounting face shall be not less than those specified in SAE-J987 (structures) and J959 (ropes) with an applied vertical load P_L that has been modified to include an out of plane side load and optionally implane off lead according to Table I for each sea state shown in the dynamic rating chart. The SAE-J987 test rated crane may be derated for additional effect of sideleads in excess of 2.7% x W_s by using calculation procedures such as those specified in SAE J1093.

6.1.2 Strength margins for land rated loads in all areas below the bottom of the slewing ring mounting face shall not be less than those specified in Section 5 of the AISC Manual of Steel Construction (Ref 9) with 1.5 P_L as the applied load, or 1.5 times the strength margin specified by SAE J987 when calculated or tested with 1.0 P_L as the applied load (see paragraph 6.1).

6.1.3. The strength margin within the swing circle assembly including fasteners shall be such that the computed stress with dead load plus 3.75 P_L shall not exceed the engineering ultimate tensile strength of the material.

6.2 Calculate P_{max}: For each W_D to be shown find P_{max}, the smallest of

$$P_{max} = \frac{P_L \cos \beta}{\cos (\beta - \alpha)}$$

which accounts for offlead when offlead is not considered in paragraph 6.1.1 or

$$P_{max} = \frac{N_p F_{BS}}{3.5}$$

which accounts for the number of parts of line where:

6.2 (Continued)

P_L = the land rated load (lb)

β = the boom angle (degrees)

α = the offlead angle (degrees)

N_P = the number of parts of line in the load hoist system

F_{BS} = the load hoist line breaking strength (lb)

6.3 Calculate W_S: Calculate the static rated load W_S where W_S is the smallest of

$$W_S = 0.75 \, P_L = \frac{P_L}{1.33}$$

which accounts for the crane components or,

$$W_S = \frac{N_P \, F_{BS}}{(1.33)(3.5)} = \frac{N_P \, F_{BS}}{4.66} \quad \frac{N_P \, F_{BS}}{5.0}$$

which accounts for the load hoist ropes. The 5.0 factor has been included to be consistent with the American Portoreum Institute (API) 2C 1983 standard.

6.4 Calculate K: For each radius to be shown calculate the vertical stiffness (spring rate) of the system, effective at the load point. The system stiffness is a function of the load line, suspension line, A-frame, boom, pedestal, and jib under service loads. Fewer components may be used as this will make the resulting ratings more conservative.

6.5 Calculate V_H: From the heave, pitch, and roll response amplitude operators supplied by the customer calculate the vertical velocity of the boom point. The absolute velocity of the hook (V_H) is determined by adding the vertical velocity of the boom point to the block hositing

TABLE I - PERCENT OFFLEAD AND SIDELEAD[a]

Beaufort Wind Force	Significant Wave Height $H_{1/3}$ (ft)	Wave Average Period $\bar{T}$ (sec)	Average Wave Length λ (ft)	Wave Instrument[b] Reading, $\bar{H}/\bar{T}$ (ft/sec)	Offlead (%)	Sidelead (%)
Static						
-	-	-	-	0	0	2.7
Dynamic						
3	1.0	2.4	20.0	0.26	6	3
4	2.9	3.9	52.0	0.46	8	4
5	6.9	5.4	99.0	0.79	12	6
6	13.0	7.0	164.0	1.15	16	8
7	23.0	8.7	258.0	1.64	22	11

[a]Alternatively,

$$\% \text{ offlead or sidelead} = \frac{(180 \text{ ft})(\% \text{ indicated})}{\text{boom tip height above boat deck}}$$

Minimum sidelead not to be less than 2.7% of static load W_s.

[b]Readings taken at the center of the Beaufort Wind Force range (Table 11-10, Ref 1).

TABLE II - MARINE CRANE RATING CHART FOR FLOATING PLATFORM

Manufacturer _____

Crane Model _____ Serial Number _____ Boom Length _____

Crane Supporting Platform _____

Distance From Platform Deck to Sea Level _____

Crane Location: Distance From Stern to Center of Rotation _____
                 Distance From Port Side to Center of Rotation _____
                 Distance From Platform Deck to Boom Foot _____

[Hoist Line: 7/8 6x25 IWRC - EIPS]

Radius (ft)	Boom Angle (deg)	Static Rating (lb)	Dynamic Ratings at Following Instrument Readings, $\bar{H}/\bar{T}$ (ft/sec)				
			0.26	0.46	0.79	1.15	1.64
Four-Part Main Hoist Line							
25	78.5	90,000	72,000	56,000	42,900	30,500	
30	75.6	90,000	69,000	56,000	42,900	30,500	
40	69.6	90,000	67,900	56,000	41,900	30,500	
50	ʋ3.3	82,000	56,300	46,900	34,700	25,400	
One-Part Whip Hoist Line							
25	80.1	22,700	18,900	16,900	16,300	13,900	11,500
30	76.1	22,700	18,900	16,900	16,300	13,900	11,500
40	70.3	22,700	18,900	16,900	16,200	13,900	11,500
50	64.0	22,700	18,400	16,500	15,800	13,400	11,000

6.5 (Continued):

speed which is the load hoist line velocity, defined in paragraph 4.18,
divided by the number of parts of line.

6.6 Calculate V_D and A_D: Using the assumptions that the work boat motion
follows the wave motion calculate the vertical velocity and acceleration
of the deck at a point directly under the boom tip. The Bretschneider
two parameter spectrum is assumed to describe the motion of the sea.

6.7 Calculate W_D: For each radius and sea state to be shown on the rating
chart calculate W_D using Equation 2. Furthermore, no W_D shall be greater
than W_S.

6.8 Rated Load Reduction. The calulated load for a given sea state shall be
adjusted so that no rated load exceeds that for a smaller operating
radius.

6.9 Calculate Swing Torque Requirement: The swing system shall be designed
to start and stop any load within rated capacity at any rotational
position of the crane, and it shall be designed to hold any load within
rated capacity against the maximum calculated or expected sidelead as
shown in Table I, and any deck inclination. Consideration must also be
given to the unloaded configuration. This provision is not in the program
described in Appendix A, although the significant pitch and roll are com-
puted in the program and printed.

7. MARINE CRANE RATING CHART FORMAT: A suggested format for a marine crane
rating chart is given in Table II. This format is suggested for use at
the discretion of each manufacturer; some suggestions and comments regard-
ing the content of this chart follow:

7.1 Each rating chart should be prepared for a fixed number of parts of load
hoist line.

7.2 Each rating chart should also indicate ratings for a whipline if the
crane is so equipped.

7.3 The wave instrument reading, $\bar{H}/\bar{T}$, is a statistical description of the sea
condition which is intended to be obtained from a wave recorder as
described in paragraph 4.3. Note that

7.3 (Continued)

$$\frac{\bar{H}}{\bar{T}} \approx 0.62 \frac{H_{1/3}}{\bar{T}}$$

where $\bar{H}$, $H_{1/3}$ and $\bar{T}$ are taken at the center of the Beaufort wind force range.

8.   <u>RATING FOR LIST</u>:   In many applications the crane is mounted on a platform (e.g., barge) that has a considerable list when a load is lifted even in calm seas. The list may be constant, or may vary as the load is swung to a different orientation on the platform. For these applications in calm seas, structural consideration must be given to sidelead and offlead. Particularly, the swing system and boom must be capable of withstanding the maximum calculated or expected sidelead. The calculations shown in Appendix A do not include rating for list.

8.1 <u>Constant List Rating (Static)</u>: These ratings are for specified list conditions when list is invariant with swing angle and no mounting vessel specifications are known. List (θ_T) is specified in degrees. The calculations in Appendix A do not include constant list rating.

8.1.1 <u>Sidelead</u>: The % sidelead to be designed for is:

$$SL = 100 (\sin \theta_T \cos \psi) + 2.7 \tag{5}$$

where: θ_T = barge list angle (deg)

         ψ = crane rotation angle (deg)

8.1.2 <u>Offlead</u>: The % offlead to be designed for is:

$$OL = 100 (\sin \theta_T \sin \psi) \tag{6}$$

8.1.3 Stresses throughout the machine are calculated at various rotation angles (ψ) to find worst combinations of OL and SL.

8.2 Variable List Rating (Near Static): The ratings are for calm sea condi-
     tions when barge mounting specifications are known. See Appendix B for
     derivation and nomenclature. Appendix A calculations do not include
     variable list rating.

8.2.1 Sidelead, Variable: The % sidelead to be designed for is:

$$SL = 100 (\cos \psi \sin \theta_T - \sin \psi \sin \theta_L) + 2.7 \qquad (7)$$

where: θ_T, θ_L, and other nomenclature are defined in Appendix B.

8.2.2 Offlead, Variable: The % offlead to be designed for is:

$$OL = 100 (\sin \psi \sin \theta_T - \cos \psi \sin \theta_L) \qquad (8)$$

8.2.3 Stresses throughout the machine are calculated at various rotation angles
       (ψ) to find worst combinations of OL and SL.

9.   PENDULATION: After the load is picked from the workboat, the continued
     boom point motion of the floating-platform-mounted crane causes pendula-
     tion of the load. Load pendulation can cause considerable damage to
     surrounding cargo, vessels, or the crane itself. It is recommended that
     tagline restraint systems be used to restrain pendulation of the load.

10. REFERENCES:

     1. J.J. Meyers, C.H. Holm, and R.F. McAllister. Handbook of ocean and
         underwater engineering. McGraw-Hill Book Company, 1969.
     2. Civil Engineering Laboratory. Technical Memorandum M-51-76-11:
         Dynamic vertical forces on a crane loading (unloading) a floating
         platform, by C.C. Ward. Port Hueneme, Calif., Sep 1976.
     3. K.V. Johnson. "Theoretical overload factor effect of sea state on
         marine cranes," paper presented at Offshore Technology Conference,
         1976. (Paper no. OTC 2584).

10. (Continued)

4. Civil Engineering Laboratory. Technical Note N-1371: The motion of
    floating advanced base components in shoal water - A comparison
    between theory and field test data, by D.A Davis and H.S. Zwibel.
    Port Hueneme, Calif., Jan 1975.

5. J.S. Bendat and A.G. Piersol. Random data: Analysis and measurement
    procedures. New York, N.Y., John Wiley and Sons, Inc., 1971.

6. M.S. Lonjuet-Higgins. "On the statistical distribution of the
    heights of sea waves," Journal of Marine Research, vol II, no. 3,
    1952, pp 245-266.

7. W.J. Pierson, Jr., G. Newman and R.W. James. Practical methods for
    observing and forecasting ocean waves by means of wave spectra and
    statistics, U.S. Navy Hydrographic Office Publication Number 603.
    Washington, D.C., 1955. Reprinted 1960, 1967.

8. J.M. Gere and W. Weaver, Jr. Analysis of framed structure. New
    York, NY, Van Nostrand Reinhold Company, 1965.

9. American Institue of Steel Construction, Inc. (AISC). "Manual of
    steel construction," Eighth Edition (or more current), Chicago, IL,
    1980.

APPENDIX A

CALCULATION OF THE DYNAMIC LOAD RATING

A.1 OBJECTIVE: The dynamic load rating will be discussed and an algorithm
     for its determination will be presented.

A.2 SCOPE: In the usual practice of lifting a load from the deck of a
     heaving ship, the crane operator begins the hoist operation at some
     arbitrary position on a wave. Because of the relationship between hoist
     speed and wave speed, the pickpoint will be assumed at a random point
     where the velocity and the acceleration of the pickpoint on the workboat
     deck can be any value, but correlated with each other.
     The workboat motion is induced by wave action, which is a function of sea
     state, hull shape, and the displacement of the boat. The common workboat
     used around offshore platforms is usually 1,500-ton displacement or less.
     Boats of this size respond strongly to the sea, and it is assumed for
     these calculations, based upon ship motion studies, that the vertical
     motion of the workboat rear quarter deck is the same as the vertical wave
     motion.
          A crane mounted on a ship or barge is subject to the motion of its
     supporting vessel. This motion induces loads on the structure that are
     not considered in land operations. The peak dynamic load is incurred
     when the load is lifted from a moving workboat. This load is a function
     of the relative velocity between the hook and the workboat deck. The
     velocity of the hook includes the hoist velocity and the velocity of the
     boom point caused by the motion of the supporting vessel.
          The response amplitude operators for the crane supporting vessel are
     assumed to be the responsibility of the customer. It is assumed that a

A.2 (Continued)

   linear ship motion theory will be employed. Rating calculations are the
   responsibility of the crane manufacturer. The sea used by the manufac-
   turer shall be described with a Bretschneider spectrum (Ref 1).

A.3 <u>APPROACH</u>: The dynamic rated load is determined from Equation 2, which
   requires values for the maximum static load, the work boat deck velocity
   and acceleration, and the hook velocity. The maximum static load (P_{max})
   is a function of the rated load including provision for sidelead for the
   entire machine (determined outside of this procedure) modified for off-
   lead and the number of parts of load hoist line. The work boat motion is
   assumed to follow the wave; therefore, the velocity and acceleration
   amplitudes are a function of $H_{1/3}$ and $\bar{T}$ and the average wave length. The
   boom point velocity amplitude is obtained by transforming the ship response
   amplitude operators to the boom point and multiplying by the appropriate
   Bretschneider spectrum. The velocity of the load hoist line is combined
   with the boom point velocity in order to get the velocity of the hook.
   A simulation of the desired motion is performed. A sinusoidal simulation
   is used to simplify the random description of the sea. The random sea
   waves are represented by a sinusoidal wave having a frequency related to
   the wave average period. The amplitudes of the wave displacement, velocity
   and acceleration are related to the significant wave height. The motion
   of the boom point is assumed to follow the supporting platform, therefore,
   the associated phase angle is zero. The motion of the work boat, under
   the boom point, is out of phase with resepct to the supporting platform
   and the boom point. This phase difference is accounted for by relating
   the horizontal distance from the center of gravity of the supporting plat-
   form to a point under the boom point, to the ocean wave average wave
   length. The dynamic rated load is calculated using values required by
   Equation 2 at 101 different locations on the simulated wave. The minimum
   dynamic rated load is selected for each operating radius shown in the
   rating chart. The algorithm details for determining the dynamic rated
   load follow.

A.3.1 <u>Algorithm</u>: The procedure that follows describes the computer program
       that is used to calculate the dynamic chart.

1. <u>Basic Input Parameters</u>: The input parameters required are defined
   in the SAE J-1366 computer program manual available from the
   society. They will not be described at this point, suffice it to
   say that the basic crane geometry, crane member properties, ship
   system properties, and other geometric and related data are
   required.

2. <u>Land Rated Load, P_{max}, and Static Rated Load</u>: The land rated load
   is the standard SAE J-987 rating for the crane with modifications
   for sidelead and optionally off lead. The standard land rated load
   with a 2.0% sidelead is modified to include each of the additional
   sideleads and optional off lead shown in Table I of the standard.
   These ratings are not determined as part of this procedure but are
   part of the input parameters along with the associated boom radius
   and boom point elevations. The off lead rating, if not previously
   considered, is determined as:

$$P_{OL} = P_L \frac{\cos \beta}{\cos (\beta - \alpha)}$$

which was determined by solving for a constant boom foot moment
using the nomenclature below:
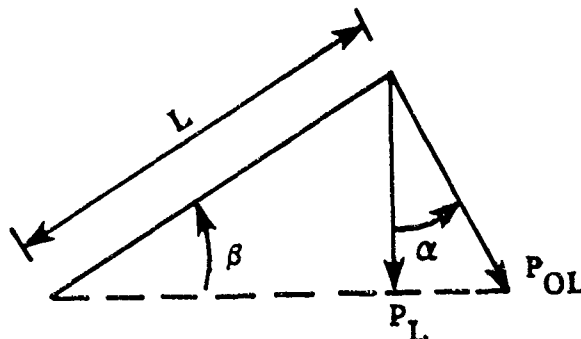
FIG. A-1 - BOOM OFFLEAD RATING EQUATION NOMENCLATURE

A.3.1 (Continued):

where: L = the length of the boom (ft)

               β = the boom angle (degrees)

               α = the offlead angle (degrees)

               P_{OL} = the offlead load that will give the same boom foot
                         moment as the vertical load (lb)

               P_{L} = the vertical load (lb)

The load line rating P_{LL} is determined from the breaking strength of the load line ropes and the number parts of line between the boom point and the hook. This value is reduced by 3.5 as specified in SAE J-959:

$$P_{LL} = \frac{N_{p} \, F_{BS}}{3.5}$$

where: N_{p} = the number of parts of line in the load hoist system

            F_{BS} = the load line breaking strength

The P_{max} term used in Equation 2 of the standard is the minimum of the offlead rating and the load line rating.

Finally, the static rated load, W_{S}, is determined so no dynamic load, W_{D}, will exceed W_{S}, where W_{S} is the smallest of:

$$W_{S} = 0.75 \, P_{L} = \frac{P_{L}}{1.33}$$

which accounts for the crane components or,

A.3.1 (Continued)

$$W_S \;=\; \frac{N_P \, F_{BS}}{(1.33)(3.5)} \;=\; \frac{N_P \, F_{BS}}{4.66}$$

which accounts for the load hoist ropes. This procedure, including replacing the constant 4.66 by 5.0, is done so the SAE ratings do not exceed those produced by the American Petroleum Institute (API-2C, 1983) ratings.

3. <u>Locate the Point of Interest Under the Boom Point</u>. Considering the general coordinate system is located at the center of gravity of the crane supporting platform. The crane may be located at an arbitrary position on the platform. The vector in the horizontal plane that locates the boom point with respect to the platform center of gravity is calculated as follows:

$$r_x \;=\; 0_r \cos (\gamma) + X_{cr}$$

$$r_y \;=\; 0_r \sin (\gamma) + Y_{cr}$$

$$r \;=\; \sqrt{r_x{}^2 + r_y{}^2}$$

$$\varepsilon \;=\; 180.0 - \frac{180.0}{\pi} \tan^{-1}\left(\frac{r_y}{r_x}\right)$$

where: 0_r = the operating radius (ft)

X_{cr}, Y_{cr} = the x and y distances between the ship cg and the center of rotation (ft)

r_x, r_y = the x and y distance to the point under the boom point in the x-y plane (ft)

γ = the swing angle with respect to the x axis (degrees)

A.3.1 (Continued)

ε = location of the r vector with respect to the
negative x axis (degrees)

4. <u>Calculate the Velocity and Acceleration of the Pick Point on the
Work Boat Deck</u>. The work boat is assumed to follow the wave. The
wave is described using the Bretschneider two parameter ($H_{1/3}$, $\bar{T}$)
spectrum. The area under this spectrum is the variance of the wave
motion for a given sea state (Ref 5). The variance (σ^2) for a zero
mean record can be converted to $a_{1/3}$ (single amplitude) or $H_{1/3}$
(double amplitude) significant wave heights by appropriate factors
(2σ and 4σ, respectively) according to Refs. 6 and 7. In this
procedure a constant amplitude sinusoidal wave is used to simulate
the motion of the work boat. The wave amplitude is $a_{1/3}$, the
frequency is derived from the average period ($\bar{T}$) of the random sea,
$\omega = 2\pi/\bar{T}$ in rad/s. The phase angle, ϕ, with respect to the center
of gravity of the supporting platform is determined by comparing a
projection of the r vector, determined in step 3, upon the average
wave length vector λ as follows:

$$\phi = 2\pi \frac{r \cos (\xi - \varepsilon)}{\lambda}$$

where: ξ = the direction of the incident waves with respect to
the negative x axis (degrees)

ε = the location of the r vector with respect to the
negative x axis (degrees)

λ = the average wave length of the impinging waves (ft)

The work boat motion with respect to time t (sec) is given by

$$D_D = a_{1/3} \sin (\omega t + \phi)$$

A.3.1   (Continued)

$$V_D = \omega \, a_{1/3} \cos(\omega t + \phi)$$

$$A_D = -\omega^2 \, a_{1/3} \sin(\omega t + \phi)$$

where: $\omega = \dfrac{2\pi}{T}$

and D_D, V_D, and A_D are the work boat deck displacement, velocity, and acceleration respectively.

5.   <u>Vertical Stiffness</u>: The vertical deflection of the crane boom tip is computed using the stiffness matrix method of analysis (Ref 8). The origin of the coordinate system used to describe the crane is the boom foot. Various members can be included in the model (the boom, pendants, and gantry, for example). The method employed uses a two dimensional model. Provision is made to permit certain crane components to change position as the boom angle changes; the mast, pendants and boom move as a unit when the boom is raised or lowered, for instance. A pedestal crane, a crawler crane, a truck crane, a ring supported crane, or any general configuration may be modeled.

   The vertical deflection of the load hoist fall is computed separately from the boom tip deflection, then the two quantities are combined. The deflection of the load hook due to the load line is:

$$\Delta_{LL} = \frac{12.0 \, P_H[B_L + N_p(D_{BP} + D_W)]}{N_p^2 \, A_R \, E_R}$$

where: Δ_{LL} = the deflection of the load line (in.)

P_H = the load on the hook, a dummy 10,000 lb load is used

B_L = the boom length (ft)

5. (Continued)

N_p = the number of parts of line

D_{BP} = the distance between the deck and the boom point (ft)

D_w = the distance between the deck and the water surface (ft)

A_R = the area of the rope (in.^{2})

E_R = the modulus of elasticity of the ropes (psi)

The vertical stiffness is computed from the deflection. The vertical boom point deflection is added to the deflection of the load hoist hook times the cosine of the offlead angle to account for offlead. Then the hook load (10,000 lb) is divided by the total vertical deflection to produce the vertical stiffness. Of course, this procedure is repeated for each boom angle shown on the load rating chart.

Vertical stiffness values are generally calculated by individual manufacturers using their own design programs. This standard uses the above procedure to make it generally applicable to all manufacturers. Alternate methods such as SAE HS J-1093, for computing the vertical stiffness are acceptable. However, appropriate modification to the rating programs would have to be done by the manufacturer.

6. Boom Point Velocity and Hook Velocity: The boom point vertical velocity is determined from the ship response amplitude operators (RAO) and the Bretschneider spectrum. The customer is responsible for providing the heave, roll, and pitch displacement RAOs. These quantities must include the modulus (absolute value) and amplitude (agrument) of the function in order to fully describe the complex number RAOs in polar form. The RAO is assumed to be determined with respect to the crane supporting platform center of gravity. The displacement RAO for the point of interest (i.e., the boom point) is computed using the appropriate transformation.

A.3.1 (Continued)

    6. (Continued)

        The displacement RAOs are converted to auto spectrum functions
    by multiplying the Bretschneider two parameter sea spectrum. The
    crane supporting platform vertical displacement RAOs for a unit wave
    are transformed to the boom point to represent the boom point vertical
    displacement. Multiplying the square of the boom point vertical dis-
    placement RAO by the Bretschneider spectrum (e.g., $H_{1/3}$ = 8.0 ft and
    $\bar{T}$ = 5.7 seconds) produces the auto spectrum (PSD) for the boom point
    vertical displacement. This displacement auto spectrum is converted
    to velocity by multiplying each ordinate by the corresponding angular
    frequency. The area under the spectrum is the variance of the
    velocity time history (assuming a zero mean velocity time history).
    The boom point velocity can be selected knowing the variance is
    related to the standard deviation by the square root function. A
    standardized variable may be used in conjunction with the standard
    deviation to give a particular value where one can be assured that
    there is a small chance of exceeding that value. For example, a
    standardized variable equal to 1.28 multiplied by the standard
    deviation of the boom point vertical velocity (V_{BP}) yields approxi-
    mately a 10% chance of exceeding that product value.

        A sinusoidal simulation of the boom point velocity, consistent
    with the simulation of the workboat can be accomplished. Using the
    standard deviation and a 1.28 standardized variable for the desired
    amplitude, the boom point vertical velocity can be simulated by V_{BP}
    cos (ωt). To this quantity for each t, $\bar{T}$/100 increments, add the
    constant load line velocity to get the velocity of the hook. Notice
    that cos (ωt) was used in order to be consistent with the workboat
    velocity simulation explained in step 4. Since the amplitude of the
    cos (ωt) term is the boom point vertical velocity, ω cos (ωt) would
    be redundant.

    7. <u>Solve for the Dynamic Rated Load</u>: The dynamic rated load is solved
        using a quadratic equation for W_D. This equation is:

$$\frac{1}{W_D} = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$

where: $A = P_{max}^2$

$$B = -2.0\, P_{max} - \frac{K\left(\dfrac{V_D + V_H}{g}\right)^2}{}$$

$$C = 1 - \left(\frac{A_D}{g}\right)^2$$

A_D = acceleration of the work boat deck (ft/s^2)

V_D = velocity of the work boat deck (ft/s)

V_H = the vertical velocity of the hook which includes the
      vertical velocity of the boom point and the load
      hoist system (ft/s)

P_{max} = (defined under step 2 above) (lb)

g = the acceleration due to gravity (ft/sec^2)

K = the vertical stiffness (lb/in.)

As with any quadratic equation there are three possibilities for
solution: (1) two equal roots ($B^2 - 4AC = 0$), (2) two real and
distinct roots ($B^2 - 4AC > 0$), and (3) conjugate complex numbers
($B^2 - 4AC < 0$). The last case is not practical for this application,
therefore it is considered erroneous.

The dynamic rated load is defined as the minimum safe load that
can be lifted at a given boom angle. Thus, the minimum value is selected
for case (1) or (2) above. Furthermore, a sinusoidal simulation of the
work boat velocity (V_D) and acceleration (A_D), and the boom point

velocity (V_{BP}) is done at $\bar{T}/100$ increments to insure the proper relation-
ship exists between these quantities and to ensure the computed load
population contains the minimum dynamic load. Lastly, the computed
dynamic rated load is compared against the static load defined in
section 2 above to ensure that this later load is not exceeded. A
provision has been added to ensure the dynamic rated load is never
larger than the dynamic rated load for smaller operating radii.

APPENDIX B

STATIC SIDE LOADING OF BARGE-MOUNTED CRANES

B.1 INTRODUCTION. Cranes operating on floating barges induce list and trim
     that vary with the slew angle of the crane, load being handled, and
     vertical and horizontal position of the unbalanced load relative to the
     metacenter. List is the angle between the plane of the barge and the
     horizon in the transverse direction, and trim is the angle between the
     plane of the barge and the horizon in the longitudinal direction.
     Because most barges are not built or loaded symmetrically, the combined
     list and trim may result in a sidelead as well as an offlead angle.
     It is the purpose of this appendix to develop a concise mathematical
     approximation for the estimation of these static side loading components
     for any arbitrary crane orientation.

B.1.1 Naval Architecture Method: To calculate the list and trim produced by
       a crane operating on a barge of known characteristics, it is first
       necessary to determine the location of the barge metacenter and the
       loads and moments with respect to the metacenter.

       1. The following assumptions are made:

       a. The crane is mounted on a rectangular, wall-sided barge. The
           weight of the barge, crane, load, and foundation is W (pounds) and
           the area of the barge at the water plane is A (ft^2).

       b. For small angles of list and trim, the changes in A are negligible.

       2. The average barge draft, d, is calculated:

B.1.1 (Continued)

2. (Continued):

$$d = \frac{W}{\lambda A} \text{ (ft)} \tag{B-1}$$

where λ is the density of seawater, 64 lb/ft^3.

3. The transverse metacentric height above the center of gravity, GM_T, is given by:

$$GM_T = BM_T - BG \tag{B-2}$$

where BG is the distance from the center of buoyancy (approximately d/2) to the center of gravity, and $BM_T = b^2/12d$, where b is the width of the barge.

4. Similarly, the longitudinal metacentric height, GM_L, is given by:

$$GM_L = BM_L - BG \tag{B-3}$$

where $BM_L = L^2/12d$, where L is the length of the barge.

5. The list angle θ_T and the triangle θ_L are given by:

$$\theta_T = \sin^{-1}\left[\frac{FM_T + RM \sin(\psi)}{W\, GM_T}\right] \tag{B-4}$$

and

$$\theta_L = \sin^{-1}\left[\frac{FM_L + RM \cos(\psi)}{W\, GM_L}\right] \tag{B-5}$$

B.1.1   (Continued)

   5.   (Continued)

   where: FM_T =   fixed moment in the transverse direction (ft-lb)

            RM   =   rotating moment (ft-lb)

            ψ =   angle of rotation of the crane with respect to the
                     longitudinal center line of the barge

B.1.2   Alternative Solution Method: Where only the barge dimensions are known,
        or the customer requests assistance from the crane manufacturer in
        selecting a proper barge size, the following method gives list and trim
        angles sufficiently accurate for final design.

   1.   The following assumptions are made:

   a.   An unbalanced load P (pounds) is applied to a rectangular wall-sided
        barge at an original radius R (feet) from barge center and a height
        H above the center of gravity of the loaded barge. It is standard
        practice, when using this method to size a barge, to take P and R
        as the total weight and center of gravity of the loaded crane
        including any counterweight and to select the values of P and R
        that produce the maximum moment about the barge centerline.

   b.   For small angles of list and trim, the changes in barge area A at
        the water plane are negligible.

   2.   Considering the barge list θ_T:

   a.   The average barge draft (and the draft at the longitudinal barge
        axis) is given by:

B.1.2 (Continued)

$$d = \frac{W}{\gamma A} \text{ (ft)} \tag{B-6}$$

where: W = total weight of balanced and unbalanced loads (lb)

γ = density of seawater, 64 lb/ft^3

b. The actual barge draft at any distance X from the longitudinal barge axis is given by:

$$d_x = d \pm x \tan (\theta_T) = \frac{W}{\gamma A} \pm x \tan (\theta_T) \tag{B-7}$$

and also by:

$$d_x = \frac{1}{\gamma} \left(\frac{W}{A} \pm \frac{M_x}{I_T} \right)$$

resulting in the equation:

$$\tan \theta_T = \frac{1}{\gamma} \frac{M}{T^I} = 0.0156 \frac{M}{I_T} \tag{B-8}$$

where I_T = barge transv$\cdots$ment of inertia = L b^3/12 (ft^4).

c. The barge list causes the momentum of P to increase such that:

$$M = P \left[R_T + H \tan \theta_T \right] = P R_T + 0.0156 \frac{M H P}{I_T}$$

$$MI_T = P R_T I_T + 0.0156 M H P$$

B.1.2 (Continued)

   c. (Continued)

$$M = \frac{P\ R_T\ I_T}{I_T - 0.0156\ H\ P} \qquad\qquad (B-9)$$

   d. Substituting into Equation B-7 provides:

$$\theta_T = \tan^{-1}\left[\frac{0.0156\ P\ R_T}{I_T - 0.0156\ H\ P}\right] \qquad (B-10)$$

   3. Similarly:

$$\theta_L = \tan^{-1}\left[\frac{0.0156\ P\ R_L}{I_L - 0.0156\ H\ P}\right] \qquad (B-10)$$

where I_L = barge longitudinal moment of inertia $L^3\ b/12$ (ft^4).

B.2 __GEOMETRY__: Assume a right-handed coordinate axis fixed at the CG of the barge with the "x" axis in the longitudinal direction as shown in Figure B-1:
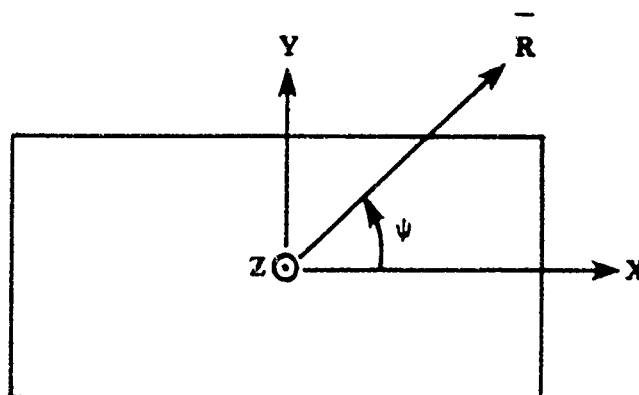
FIG. B-1 - BARGE COORDINATE SYSTEM.

B.2 (Continued)

The unit vector, $\bar{R}$, indicates the orientation of the crane boom and the rotating moment,

$$\bar{R} = \cos{(\psi)}\,\hat{i} + \sin{(\psi)}\,\hat{j}$$

where $\hat{i}$, $\hat{j}$, and $\hat{k}$ are unit vectors in the x, y, and z directions, respectively.

Allow the barge to undergo a small angular rotation about the "x" and "y" axes, θ_T and θ_L, respectively as shown in Figure B-2:

X axis rotation   **Y axis rotation**
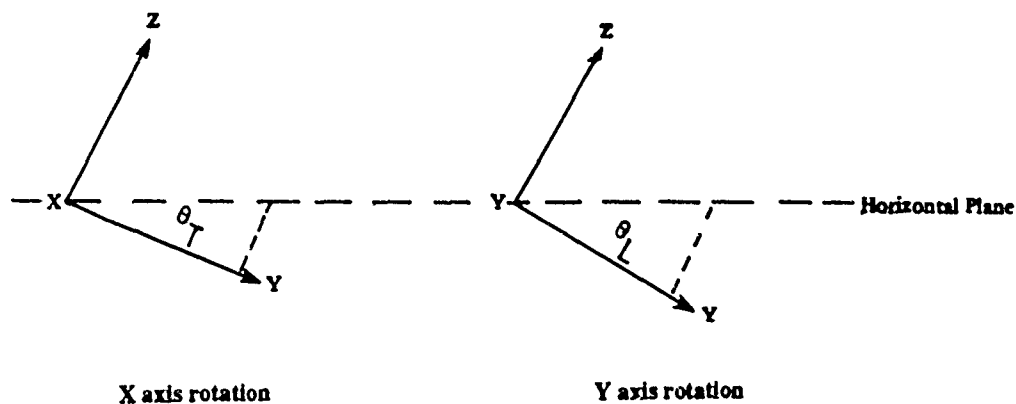
FIG. B-2. BARGE TRIM AND LIST ANGLES.

It can readily be seen that the horizontal plane passes through the three points $\{0,0,0\}$, $\{\cos{(\theta_L)},\ 0,\ \sin{(\theta_L)}\}$, and $\{0,\ \cos{(\theta_T)},\ \sin{(\theta_T)}\}$, resulting in the equation,

$$\begin{vmatrix} x & y & z \\ \cos{(\theta_L)} & 0 & \sin{(\theta_L)} \\ 0 & \cos{(\theta_T)} & \sin{(\theta_T)} \end{vmatrix} = 0$$

$$x \sin{(\theta_L)}\cos{(\theta_T)} + y \sin{(\theta_T)}\cos{(\theta_L)} - z \cos{(\theta_L)}\cos{(\theta_T)} = 0$$

B.2 (Continued)

The horizontal plane has a perpendicular vector, $\bar{V}$, which represents the direction of gravity.

$$\bar{V} = \sin(\theta_L) \cos(\theta_T) \hat{i} + \sin(\theta_T) \cos(\theta_L) \hat{j} - \cos(\theta_L) \cos(\theta_T) \hat{k}$$

$$- \bar{V} \cdot \hat{k} = |\bar{V}| \cos(\theta_M) = \cos(\theta_L) \cos(\theta_T)$$

where: $|\bar{V}|$ is the absolute value of $\bar{V}$.

$$|\bar{V}| = \sqrt{\cos^2(\theta_L) + \cos^2(\theta_T) - \cos^2(\theta_L) \cos^2(\theta_T)}$$

and θ_M is the maximum combined angle between the barge and the horizontal. For small angles, $\bar{V} = 1$; therefore:

$$\theta_M = \cos^{-1}\left[\cos(\theta_L) \cos(\theta_T)\right]$$

The side loading on the crane is given by the triple scaler product,

$$S = \frac{\bar{V}}{|\bar{V}|} \cdot \hat{k} \times \bar{R}$$

$$S = \frac{\cos(\psi) \sin(\theta_L) \cos(\theta_L) - \sin(\psi) \sin(\theta_T) \cos(\theta_T)}{\cos^2(\theta_L) + \cos^2(\theta_T) - \cos^2(\theta_L) \cos^2(\theta_T)}$$

A positive value of S indicates counterclockwise loading of the boom.

Once again, for small angles of θ_L and θ_T, the expression can be simplified to:

$$S\% = 100\left[\cos(\psi) \sin(\theta_T) - \sin(\psi) \sin(\theta_L)\right]$$

B.3 <u>REFERENCES</u>

1. V.L. Streeter. Fluid mechanics. McGraw-Hill Book Co., 1966.

2. T.C. Gillmer. Fundamentals of construction and stability of Naval ships, United States Naval Institute. 1969.

SECTION II
CRANE RATING COMPUTER PROGRAM

DISCLAIMER

This program is furnished by the Society of Automative Engineers and is accepted and used by the recipient with the express understanding that the Society makes no warranties, expressed or implied, concerning the accuracy, completeness, reliability, usability, or suitability for any particular purpose of the information and data contained in this program or furnished in connection therewith, and the Society shall be under no liability whatsoever to any person by reason of any use made thereof. The program belongs to the Society. Therefore, the recipient further agrees not to assert any proprietary rights therein or to represent this program to anyone as other than a Society program.

1.   OBTAINING THE CRANE RATING PROGRAM: The SAE J 1366 recommended practice
     for rating lift cranes operating in the ocean environment has been imple-
     mented in a computer program. This program can be obtained from the
     Society of Automotive Engineers:

          Society of Automotive Engineers
          400 Commonwealth Drive
          Warrendale, PA 15096-0001

          The program was developed using FORTRAN following the ANSI X3.9-1978
     full language standard. Most people refer to this standard as FORTRAN 77.
     Therefore, the program can be easily installed on any computer that has a
     FORTRAN compiler that implements the full language ANSI standard.
          The program, a test problem, and typical supporting platform
     response operators can be purchased from the Society. This information
     will be delivered on a 360K byte, double sided, double density, 5.25-inch
     diskette which can be read by any of the IBM compatible microcomputers.

The program can then be installed on the microcomputer or it can be tele-communicated to a larger machine using any terminal emulator such as PC-TALK III or CROSSTALK.

The SAE J 1366 diskette will contain the following files:

a. Program source statements, 6 files:

BOAT.FOR
BPVEL.FOR
FRAME.FOR
FREQ.FOR
SAEJ1366.FOR
SOLVE.FOR

b. The crane test problem used in this report, 1 file:

EXAM4000.DAT

c. A library of platform RAO's for the C3, C4, C5, ... C7 ship and DELONG A and B barge platforms, 6 files:

C3.RAO
C4.RAO
C5.RAO
C7.RAO
DELONGA.RAO
DELONGB.RAO

d. An executable file for the IBM-PC. This file was prepared using the Ryan-McFarland (IBM Professional) FORTRAN compiler. The program requires a math co-processor and 360K of memory.

SAEJ1366.EXE

2. <u>USING THE CRANE RATING PROGRAM</u>: When the program begins to run, the following questions will be asked of the user at his terminal:

<NAME OF CRANE DATA FILE>

    Reply with the crane data file name without typing the required
extension .DAT (e.g. EXAM4000 for EXAM4000.DAT)

<TYPE OF RATING, FIXED OR MOVING PLATFORM>

    Reply with either FIXED or MOVING. This option permits running the
problem without the effects of the crane supporting platform motion,
a quasi SAE J1238 rating.

<NAME OF SHIP RAO DATA FILE>

    Reply with the RAO data file name without typing the required
extension .RAO (e.g. C3 for C3.RAO).

    We have found that it is very easy to create either the crane data
file (name.DAT) or the RAO data file (name.RAO) using a screen editor or
word processing program. However, certain features should be supported.
The left hand tab feature makes it possible to easily insert floating
point numbers and character strings in their required fields, the right
hand tab likewise makes it very easy to insert integer numbers. A char-
acter file (American National Standard Code for Information Interchange
(ASCII), ANSI X3.4-1977 codes 32 through 122) with embedded blanks
instead of tab controls must be produced so the SAE rating program can
recognize the data in the file. A users manual is included showing how
to set the required tabs for the crane and RAO data files.

3.   <u>CRANE MODELING GUIDE</u>: The crane, plane frame, model is used to determine
the vertical stiffness in the plane of the boom. The model may be as
complete as desired; however, simple models will produce more conservative
ratings. Each crane component is represented by a single beam element,
such as the boom, pendants, and boom hoist, with appropriate equivalent
section and material properties. Various machine configurations can be
represented as shown in Figure 3:
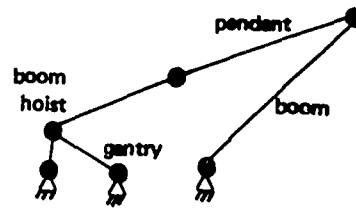
(a) Crawler or truck with a floating harness.
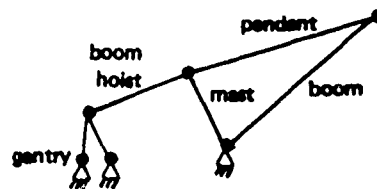
(b) Crawler or truck with a mast.
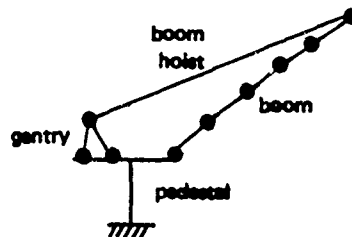
(c) Pedestal mounted marine crane.

FIG. 3 - PLANE FRAME CRANE MODELS FOR
VARIOUS MACHINE CONFIGURATIONS.

If desired, a component, the marine crane boom for example, can be modeled with more than one beam element, each with different equivalent section properties.

The plane frame model of the crane may be replaced by the manufacturer. Each manufacturer has their own methods to compute the vertical stiffness of the crane, these methods may be used, however, the computer program and user manual will have to be appropriately modified.

4.   COMPUTER PROGRAM MANUAL: The computer program manual that follows describes the typical line of data input. The data are organized in a fixed format style instead of the free format style. This format has been chosen because checking columnar data, characteristics of the fixed

4.   (Continued).

form, reduces input errors. Furthermore, a screen editor or word
processing program with left, right, and decimal tabulation features
facilitate preparing these files.

There are two files used to input the data, each will be described
below. The first file contains basic crane descriptive data as well as
general problem parameters. The second file provides the platform motion
data. These data are the amplitude response operators: heave, roll, and
pitch for the supporting platform. Table III provides a description of
each type of data input line with associated tabulation stops. The
definition of each variable name is listed below. Figures 2 and 4
provide a pictorial definition for some of the variable names.

4.1 Crane Data File: The crane data file contains the problem parameters
that describe the crane and other pertinent data. The name of the data
file should reflect the name of the crane that is being rated. Eight
characters are used plus the extension .DAT. (e.g., EXAM4000.DAT).

4.1.1 Rating parameter input line type A:

Column	Variable	Description
1-40	MANUFAC	Name of manufacturer, 40 characters maximum
41-50	CRANE	Crane name, 10 characters maximum
51-60	SERIAL	Crane serial number, 10 characters maximum

4.1.2 Rating parameter input line type B:

Column	Variable	Description
1-10	BETA	Wave direction (degrees) with respect to the stern, counterclockwise. This angle must coincide with the wave direction angle used to describe the ship motion data described hereafter.
11-20	DEPTH	Depth of water in feet.
21-30	ALPHA	Swing angle (degrees) with respect to the stern, counterclockwise.
31-40	LINSPD	Velocity (ft/min) of the load hoist line at the drum, positive up.

TABLE III – DATA FILE INPUT RECORD FORMAT

CRANE DATA FILE - NAMED _____.DAT

A

1 MANUFAC		41 CRANE	51 SERIAL	

B

BETA (deg) 10	DEPTH (ft) 20	ALPHA (deg) 30	LINSPD (ft;min) 40	

C

DKELV (ft) 10	BL (ft) 20	CRBF (ft) . 30	DKBF (ft) 40	CRX (ft) 50	CRY (ft) 60	AROPE (in.^{2}) 70	EROPE (psi) 80

D

BRKSTR (lb) 10	NUMPRT 20	

E

NM 10	NJ 20	NUMRAD 30	LEDOFF 40	

REPEAT NJ TIMES

F

X (ft) 10	Y (ft) 20	X RST 30	Y RST 40	Z RST 50	ICOR 60	62 NODE ID

REPEAT NM TIMES

G

JJ 10	JK 20	JMER 30	KMER 40	AR (in.^{2}) 50	IZ (in.^{4}) 60	E (psi) 70	72 MEMBRID

REPEAT NUMRAD TIMES

H

BRAD (ft) 10	BPLEV (ft) 20	SLAND 2.7% (lb) 30	PLAND (lb) FOR SIDE LEAD				
			3% 40	4% 50	6% 60	8% 70	11% 80

SHIP MOTION FILE - NAMED _____. RAO

I

FRQMIN (rad/sec) 10	FRQMAX (rad/sec) 20	NUMFRQ 30	32 NAMSHP 70	

REPEAT NUMFRQ TIMES

J

DZ (ft/ft) 10	PHI (rad/ft) 20	THE (rad/ft) 30	AZ (rad) 40	APHI (rad) 50	ATHE (rad) 60	

4. (Continued)
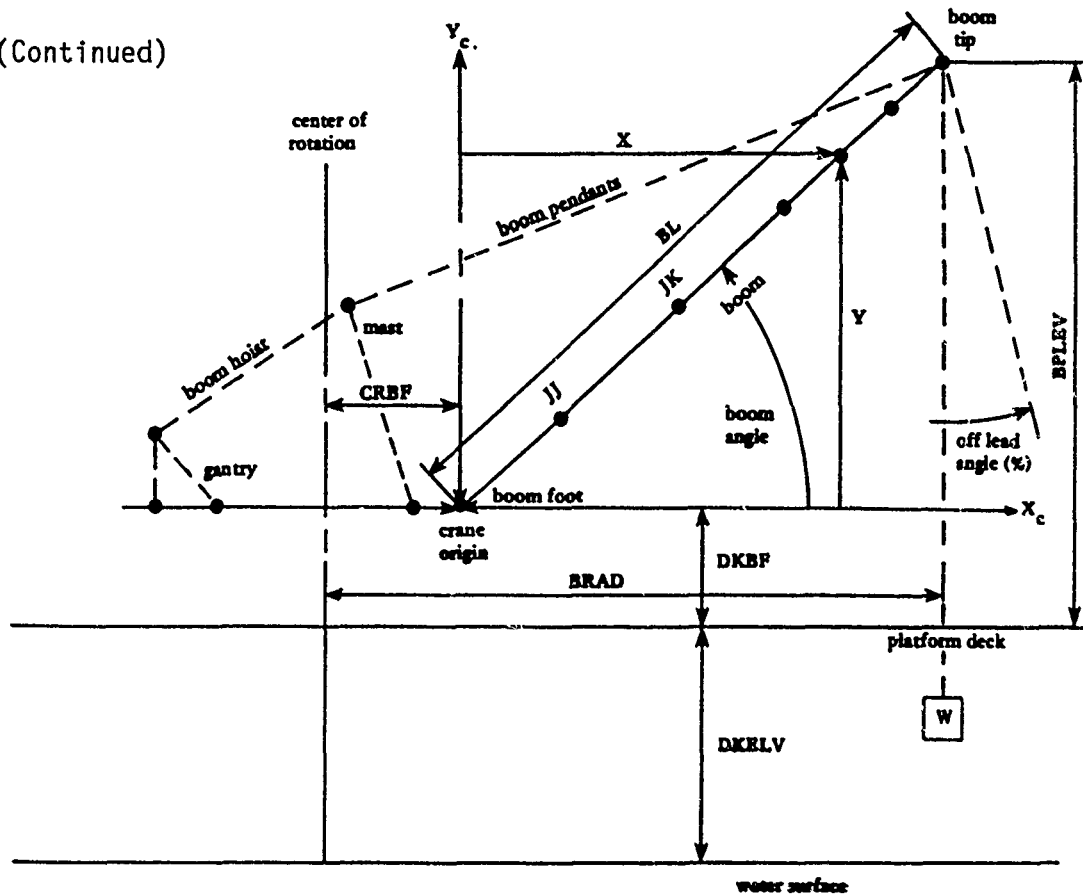
FIG. 4 - TWO-DIMENSIONAL CRANE MODEL NOMENCLATURE.

4.1.3 Rating parameter input line type C:

Column	Variable	Description
1-10	DKELV	Deck elevation above the water surface (ft)
11-20	BL	Boom length (ft)
21-30	CRBF	Center of rotation to boom foot (ft)
31-40	DKBF	Deck to boom foot (ft)
41-50	CRX	Platform CG to center of rotation of crane in the X direction (ft)
51-60	CRY	Platform CG to center of rotation of the crane in the Y direction (ft)
61-70	AROPE	Cross section area of load hoist rope (in.^{2})
71-80	EROPE	Modulus of elasticity of load hoist rope (psi)

4.1.4 Rating parameter input line type D:

Column	Variable	Description
1-10	BRKSTR	Load hoist rope breaking strength (lbs)
11-20	NUMPRT	Number of parts of load hoist line

4. (Continued)

4.1.5 Crane size input line type E:

Column	Variable	Description
1-10	NM	Number of members in the crane model, (maximum 50).
11-20	NJ	Number of nodes in the crane model, (maximum 50).
21-30	NUMRAD	Number of operation radii (boom angles) in the rating chart, (maximum 20).
31-40	LEDOFF	Has off lead been considered in the land rating chart input data below? Yes or No

The crane is described using the notion of nodes and members common to most matrix methods for framed structures analysis (Ref 8). The model is a plane frame model. This means the displacements are restricted to a single plane defined by rectangular coordinates. Each member in the plane frame model is defined by two nodes, one at each member end. Thus, the total number of members are determined by counting the node pairs defining the member ends.

4.1.6 Crane geometry input, lines type F, repeated NJ times.

Column	Variable	Description
1-10	X	X coordinate of a node in the crane model, feet.
11-20	Y	Y coordinate of a node in the crane model, feet.
21-30	XRST	X restraint for a node 1 is fixed, 0 is free.
31-40	YRST	Y nodal translational restraint for a joint, 1 is fixed, 0 is free.
41-50	ZRST	Rotational restraint about the z axis (Z = X cross Y), 1 is fixed, 0 is free.
51-60	ICOR	0 Signifies the node is independent of changes in the boom angle. 1 Signifies the node will rotate with changes in boom angle. 2 Signifies the top of the gantry **Mast configurations** Models with a mast require the boom, pendent, and mast move as a triangle. Therefore, ICOR = 1 for nodes on the boom and the mast including the boom and mast tip nodes. **Floating harness configurations** 3 Signifies the location of the flc ing harness boom hoist sheaves. The boom pen ent is located between the ICOR = 3 node and the last node in the list which must be the boom tip node.
62-80	NODEID	The description of the node point, 19 characters maximum.

4. (Continued)

The nodes are defined by coordinates in a rectangular coordinate system having its origin at the boom foot pin. Each node is described by x,y pairs denoting the horizontal (x) and vertical (y) distances from the boom foot. It is customary to have the positive x axis to the right of the observer and the positive y axis vertical. This coordinate system is tied to the ship coordinate system through the variables CRBF, DKBF, CRX, and CRY. Each node may be free to translate or rotate in space. If one desires, the nodes may be restricted from translation, x or y, and rotation. Some nodes, the boom tip, the mast tip or optional intermediate nodes in the boom must follow the changes in boom angle. The ICOR provision accomplishes this requirement. The last node in the list must define the coordinate of the boom tip. This location is also the place where the load is applied.

4.1.7 Crane member input, lines type G, repeated NM times.

Column	Variable	Description
1-10	JJ	Node number for the member at end A.
11-20	JK	Node number for the member at end B.
21-30	JMER	Member end release for the end A, 0 the end is fixed or 1 the end is released.
31-40	KMER	Member end release for the end B, 0 the end is fixed or 1 the end is released.
41-50	AR	Member area (in.^{2}).
51-60	IZ	Moment of inertia about the member z axis (in.^{4}).
61-70	E	Modulus of elasticity for the member (lb/in.^{2}).
72-80	MEMBRID	Member description, maximum 9 characters.

A crane member is defined by two nodal end points, one at end A and the other at end B. For example, the boom may be described by a node at the boom foot, end A, and a node at the boom tip, end B. This would be one member. The boom may also be described as a series of members; a base, 10-foot insert, 20-foot insert and a tip, for example. In this case there would be four members described by five nodes. Each member end is assumed to have three reactions: a normal force, a shear force, and a moment. There are occasions where the moment may not be desired

4. (Continued)

(released), therefore, a member end release feature is provided. This
feature permits the node to be free to rotate but restricts the member
from carrying a moment at the specified end.

4.1.8 Land crane rating chart input, lines type H, repeated NUMRAD times.

Column	Variable	Description
1-10	BRAD	Operating radius (ft)
11-20	BPELV	Boom point elevation (ft)
21-30	SLAND	Static land rating (lb) for 2.7% sidelead
31-40	PLAND(1)	Static land rating (lb) for 3% sidelead
41-50	PLAND(2)	Static land rating (lb) for 4% sidelead
51-60	PLAND(3)	Static land rating (lb) for 6% sidelead
61-70	PLAND(4)	Static land rating (lb) for 8% sidelead
71-80	PLAND(5)	Static land rating (lb) for 11% sidelead

The land rating chart for the crane is described. The operating
radius is measured from the center of rotation and the boom point
elevation is measured from the ground for land cranes or deck for marine
cranes. The static land rated load is the static rating for the crane
excluding load hoist ropes for each operating radius. A static land
rating is required for each of the sidelead and offlead (optional) values
listed in Table I.

4.2 Ship Motion Data File: The ship motion data file is supplied by the
customer. The file name should represent the ship being used. Eight
characters with the extension .RAO form the complete file name (e.g.,
NEVRSAIL.RAO). It contains the response amplitude operators for the ship
or platform that will support the crane to be rated. Each set of
response amplitude operators is dependent upon the wave direction (BETA)
of the incident wave.

4.2.1 Ship motion parameter line type I:

Column	Variable	Description
1-10	FRQMIN	Minimum angular wave frequency in radians per second which is associated with the first ship motion operator value.

4.   (Continued)

11-20	FRQMAX	Maximum angular wave frequency in radians per second which is associated with the last ship motion operator value.
21-30	NUMFRQ	Number of angular wave frequency values used to obtain the ship motion operators, which is also the number of ship motion operators values (maximum 80).
32-70	NAMSHP	Name of the supporting platform, 39 characters maximum.

4.2.2 Ship motion input, lines type J, each motion fuction has NUMFRQ values:

Column	Variable	Description
1-10	DZ	Heave motion response operator (ft/ft).
11-20	PHI	Roll motion response operator (radians/ft).
21-30	THE	Pitch motion response operator (radians/ft).
31-40	AZ	Heave phase angle (radians).
41-50	APHI	Roll phase angle (radians).
51-60	ATHE	Pitch phase angle (radians).

5.   EXAMPLE PROBLEM: An example problem producing the rating for a typical mast configured crane supported on a C3 hull is presented to illustrate how to prepare the data for the SAE J1366 program.

5.1   Sea Characteristics: The characteristics of various sea states are presented in Table IV. The table has been presented to help SAE J1366 users relate to sea chracteristics required in the rating procedure.

5.2   Ship and Barge Characteristics: Ship and barge characteristics for typical crane support platforms are presented in Table V. SAE J1366 requires the customer to provide the response amplitude operators (RAO) for the crane support vessel. RAOs for the vessels listed in Table V are included with SAE J1366 program to allow the user to gain experience rating the example crane on various platforms.

The RAOs for the platforms listed in Table V were prepared for 135° incident wave direction. The RAOs for the C3, C4, C5, and C7 vessels and the DeLong Type A and B barges were prepared using the relative motion program RELMO developed by NCEL. RELMO uses a linear strip theory to compute the RAOs.

TABLE IV - WIND AND SEA SCALE FOR FULLY ARISEN SEA

[From J.J. Meyers, C.H. Holm, and R.F McAllister. Handbook of ocean and underwater engineering. New York, N.Y., McGraw-Hill Book Company, 1969, pp. 11-98L]

Sea state	Description	Wind Beaufort wind force	Wind Descrption	Wind Range, knots	Wind Wind velocity, knots***	Sea Average	Sea Significant	Sea Average 1/10 highest	Sea Significant range of periods, sec	Sea Tmax, period of maximum energy of spectrum	Sea T̄ Average period	Sea T Average wavelength	Sea Minimum fetch, nmi	Sea Minimum duration, hr
0	Sea like a mirror.	0	Calm	<1	0	0	0	0						
	Ripples with the appearance of scales are formed, but without foam crests.	1	Light airs	1-3	2	0.05	0.08	0.10	up to 1.2 sec	0.7	0.5	10 in.	5	18 min
1	Small wavelets, still short but more pronounced; crests have a glassy appearance, but do not break.	2	Light breeze	4-6	5	0.18	0.29	0.37	0.4-2.8	2.0	1.4	6.7 ft	8	39 min
	Large wavelets, crests begin to break, foam of glassy appearance. Perhaps scattered white horses.	3	Gentle breeze	7-10	8.5	0.6	1.0	1.2	0.8-5.0	3.4	2.4	20	9.8	1.7 hr
2					10	0.88	1.4	1.8	1.0-6.0	4.0	2.9	27	10	2.4
	Small waves, becoming larger; fairly frequent white horses.	4	Moderate breeze	11-16	12	1.4	2.2	2.8	1.0-7.0	4.8	3.4	40	18	3.8
3					13.5	1.8	2.9	3.7	1.4-7.6	5.4	3.9	52	24	4.8
					14	2.0	3.3	4.2	1.5-7.8	5.6	4.0	59	28	5.2
					16	2.9	4.6	5.8	2.0-8.8	6.5	4.6	71	40	6.6
4	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray).	5	Fresh breeze	17-21	18	3.8	6.1	7.8	2.5-10.0	7.2	5.1	90	55	8.3
5					19	4.3	6.9	8.7	2.8-10.6	7.7	5.4	99	65	9.2
					20	5.0	8.0	10	3.0-11.1	8.1	5.7	111	75	10
	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray)	6	Strong breeze	22-27	22	6.4	10	13	3.4-12.2	8.9	6.3	134	100	12
					24	7.9	12	16	3.7-13.5	9.7	6.8	160	130	14
6					24.5	8.2	13	17	3.8-13.6	9.9	7.0	164	140	15
					26	9.6	15	20	4.0-14.5	10.5	7.4	188	180	17
	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind (spindrift begins to be seen).	7	Moderate gale	28-33	28	11	18	23	4.5-15.5	11.3	7.9	212	230	20
					30	14	22	28	4.7-16.7	12.1	8.6	250	280	23
7					30.5	14	23	29	4.8-17.0	12.4	8.7	258	290	24
					32	16	26	33	5.0-17.5	12.9	9.1	285	340	27
	Moderately high waves of greater length; edges of crests break into spindrift. The foam is blown in well-marked streaks along the direction of the wind. Spray affects visibility.	8	Fresh gale	34-40	34	19	30	38	5.5-18.5	13.6	9.7	322	420	30
					36	21	35	44	5.8-19.7	10.3	10.3	363	500	34
					37	23	37	46.7	6.0-20.5	14.9	10.5	376	530	37
					38	25	40	50	6.2-20.8	15.4	10.7	392	600	38
8					40	28	45	58	6.5-21.7	16.1	11.4	444	710	42
	High waves Dense streaks of foam along the direction of the wind. Sea begins to roll. Visibility affected.	9	Strong gale	41-47	42	31	50	64	7.0-23	17.0	12.0	492	830	47
					44	36	58	73	7.0-24.2	17.7	12.5	534	960	52
					46	40	64	81	7.0-25	18.6	13.1	590	1110	57
	Very high waves with long overhanging crests. The resulting foam is in great patches and is blown in dense white streaks along the direction of the wind. On the whole, the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shock-like. Visibility is affected.	10	Whole gale*	48-55	48	44	71	90	7.5-26	19.4	13.8	650	1250	63
9					50	49	78	99	7.5-27	20.2	14.3	700	1420	69
					51.5	52	83	106	8.0-28.2	20.8	14.7	736	1560	73
					52	54	87	110	8.0-28.5	21.0	14.8	750	1610	75
					54	59	95	121	8.0-29.5	21.8	15.4	810	1800	81
	Exceptionally high waves (small and medium-sized ships might for a long time be lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.	11	Storm*	56-63	56	64	103	130	8.5-31	22.6	16.3	910	2100	88
					59.5	73	116	148	10-32	24	17.0	985	2500	101
	Air filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	12	Hurricane*	64-71	>64	>80**	>128**	>164**	10-(35)	(26)	(18)	-	-	-

*For hurricane winds (and often whole gale and storm winds) required durations and fetches are rarely attained. Seas are therefore not fully arisen

**For such high winds, the seas are confused. The wave crests blow off, and the water and the air mix.

***A heavy box around this value means that the values tabulated are at the center of the Beaufort range.

Source: W.A. McEwen and A.H. Lewis, "Encyclopedia of Nautical Knowledge," p.483, Cornell Maritime Press, Cambridge, Md., 1953 "Manual of Seamanship," pp.717-718, vol II Admiralty, London, H.M. Stationery Office, 1952 Pierson, Newmann, James, "Practical Methods for Observing and Forecasting Ocean Waves." New York University College of Engineering, 1953

5.2 (Continued)

Figures 4 through 9 show the RAO functions with respect to wave period. Table VI is the C3.RAO data file that was used in the example problem.

5.3 Crane and Supporting Platform Model: Data preparation notes for the support platform and the crane are presented to help the user understand how to use Table III.

5.3.1 Ship Geometry: The ship geometry for the EXAM4000 test problem is shown in Figure 11. The ship's geometry variables listed in Table III of the SAE J1366 program user manual are represented. Figure 11 should be correlated with the EXAM4000.DAT file listing. See Table VI how to prepare the ship's geometry data.

TABLE V - CHARACTERISTICS FOR TYPICAL
CRANE SUPPORTING VESSELS

Class	Length (ft)	Beam (ft)	Displacement ($lb \times 10^6$)
Ships			
C3	470	69	31.9
C4	540	82	46.8
C5	582	78	55.2
C7	670	85	44.8
Barges			
De Long Type A	296	80	3.75
De Long Type B	150	60	1.46

TABLE VI – TYPICAL RAO DATA FILE – C3.RAO FOR THE C3 HULL
WITH A 135° INCIDENT WAVE DIRECTION

LINE TYPE	1	2	3	4	5	6
	1234567890	1234567890	1234567890	1234567890	1234567890	1234567890	123456789
I	0.1050	4.0000	80 C3 HULL			
J-1	0.9910	0.0010	0.0020	0.0040	1.6690	1.6000
J-2	0.9780	0.0020	0.0030	0.0070	1.7200	1.6160
J-3	0.9580	0.0030	0.0030	0.0120	1.7790	1.6340
J-4	0.9310	0.0040	0.0040	0.0170	1.8490	1.6540
J-5	0.8970	0.0050	0.0050	0.0220	1.9360	1.6770
J-6	0.8550	0.0070	0.0060	0.0250	2.0440	1.7040
J-7	0..8040	0.0100	0.0060	0.0250	2.1790	1.7340
J-8	0.7470	0.0140	0.0070	0.0220	2.3570	1.7690
J-9	0.6820	0.0240	0.0080	0.0110	2.6240	1.8110
J-10	0.6120	0.0460	0.0080	-0.0110	-3.0940	1.8630
.						
.						
.						
J-60	0.0000	0.0000	0.0000	-1.3080	-2.2470	-2.5290
J-61	0.0010	0.0000	0.0000	-1.0920	-2.6480	-0.0590
J-62	0.0000	0.0000	0.0000	-0.8540	2.3950	0.5920
J-63	0.0000	0.0000	0.0000	2.2570	0.9520	0.8730
J-64	0.0000	0.0000	0.0000	2.3340	0.5280	-2.4590
J-65	0.0000	0.0000	0.0000	2.1930	-0.6420	-2.2490
J-66	0.0000	0.0000	0.0000	-0.4600	-2.1220	-2.7500
J-67	0.0000	0.0000	0.0000	-1.1770	-2.3200	0.6580
J-68	0.0000	0.0000	0.0000	0.0600	-1.5680	-0.9010
J-69	0.0000	0.0000	0.0000	-0.1030	-1.5400	1.8610
J-70	0.0000	0.0000	0.0000	-2.8830	1.2870	1.3690
J-71	0.0000	0.0000	0.0000	1.5660	-0.8520	-1.6540
J-72	0.0000	0.0000	0.0000	0.1860	-1.5920	-1.5120
J-73	0.0000	0.0000	0.0000	0.7320	-0.5930	0.8340
J-74	0.0000	0.0000	0.0000	1.0740	-0.5310	-2.1080
J-75	0.0000	0.0000	0.0000	-0.7380	-2.0820	2.8430
J-76	0.0000	0.0000	0.0000	-1.9660	2.6300	1.9480
J-77	0.0000	0.0000	0.0000	-2.7570	1.3710	-0.3790
J-78	0.0000	0.0000	0.0000	1.3470	-0.5990	-0.7410
J-79	0.0000	0.0000	0.0000	0.8910	-1.8240	2.8170
J-70	0.0000	0.0000	0.0000	-1.7020	2.1590	2.8590

*Table III in the SAE J1366 user manual defines the variables for the
ship motion data presented here.
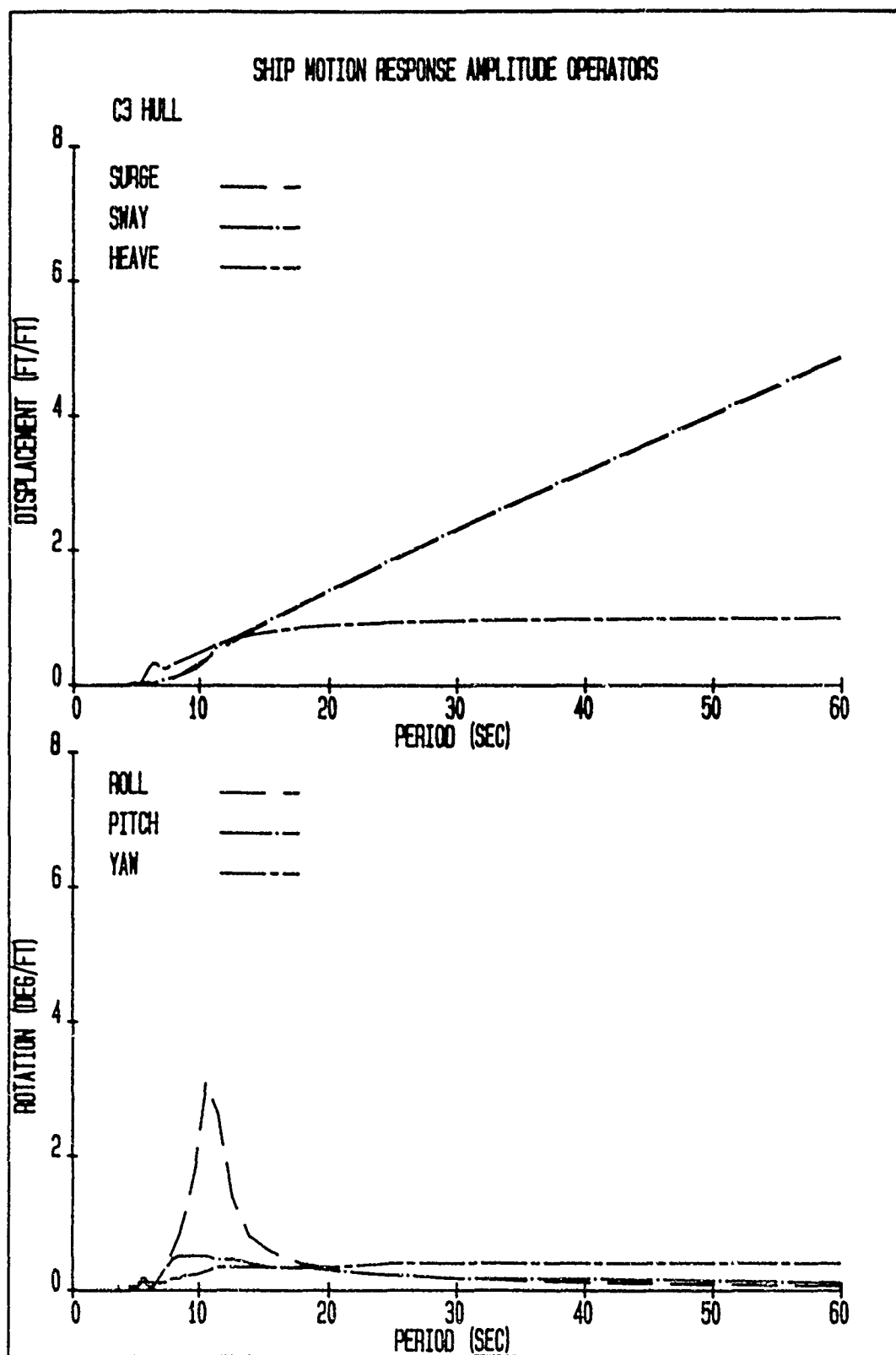
FIG. 5 - TYPICAL C3 RESPONSE AMPLITUDE OPERATORS.
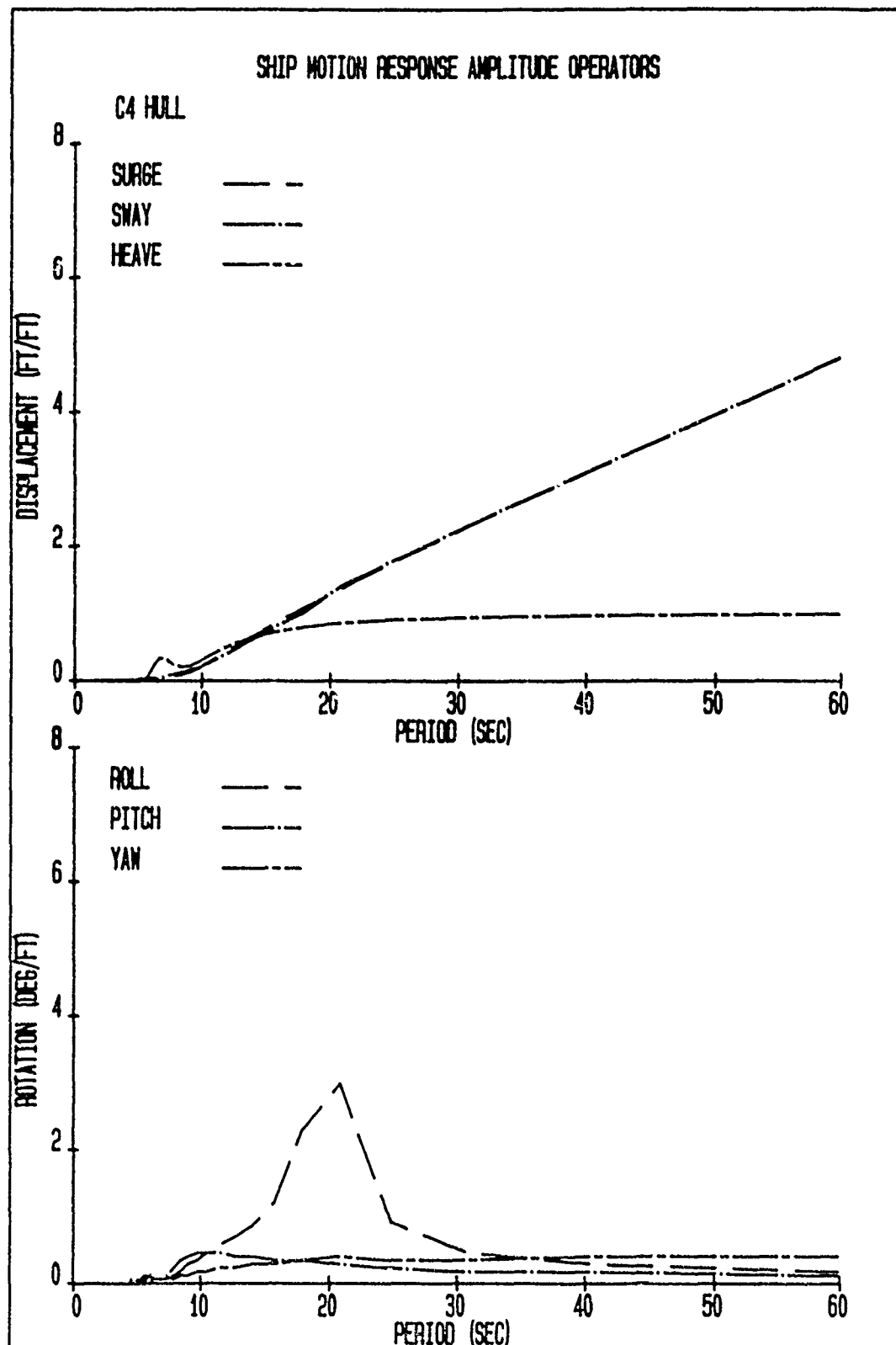
FIG. 6 - TYPICAL C4 RESPONSE AMPLITUDE OPERATORS.
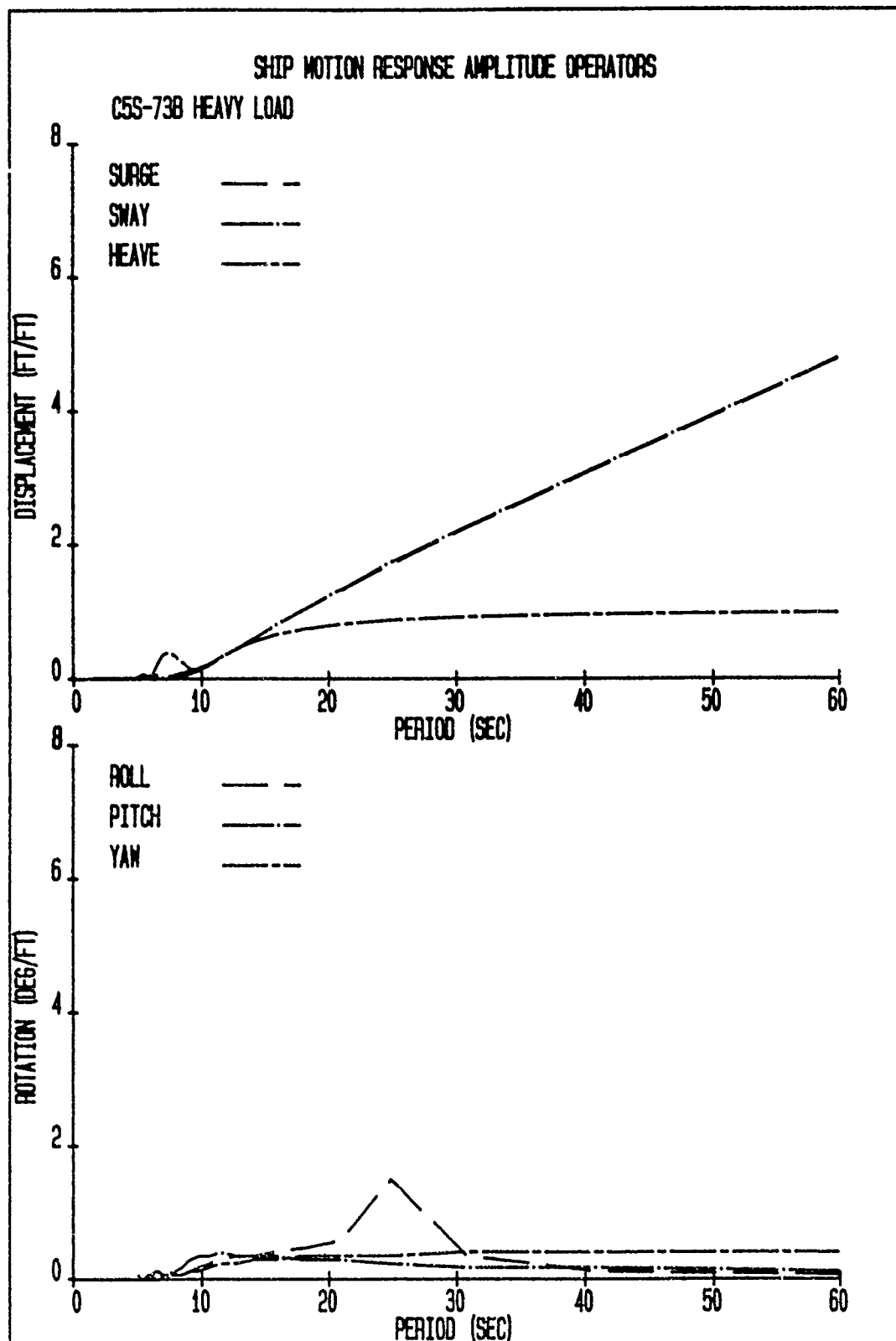
FIG. 7 - TYPICAL C5 RESPONSE AMPLITUDE OPERATORS.
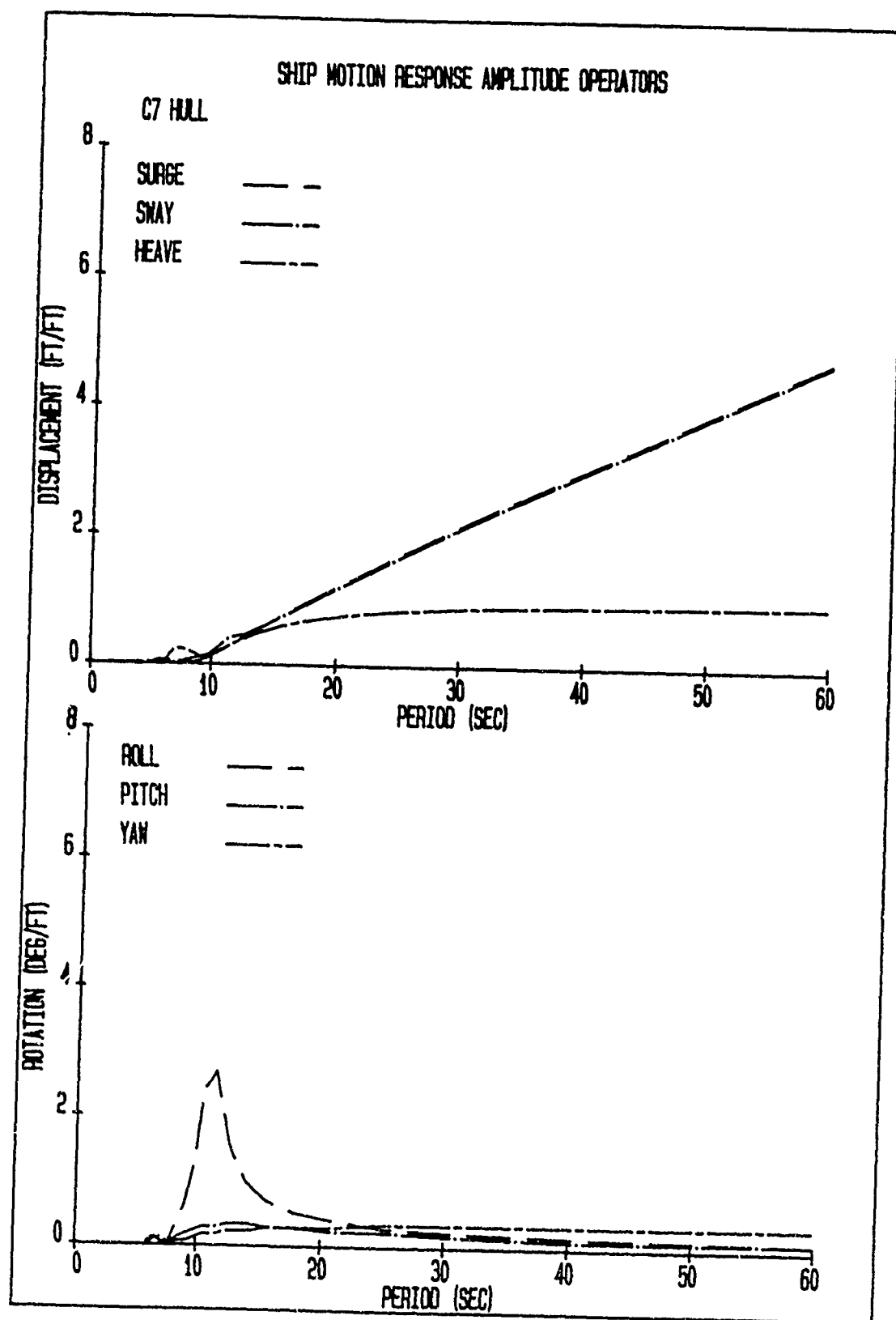
FIG. 8 - TYPICAL C7 RESPONSE AMPLITUDE OPERATORS.
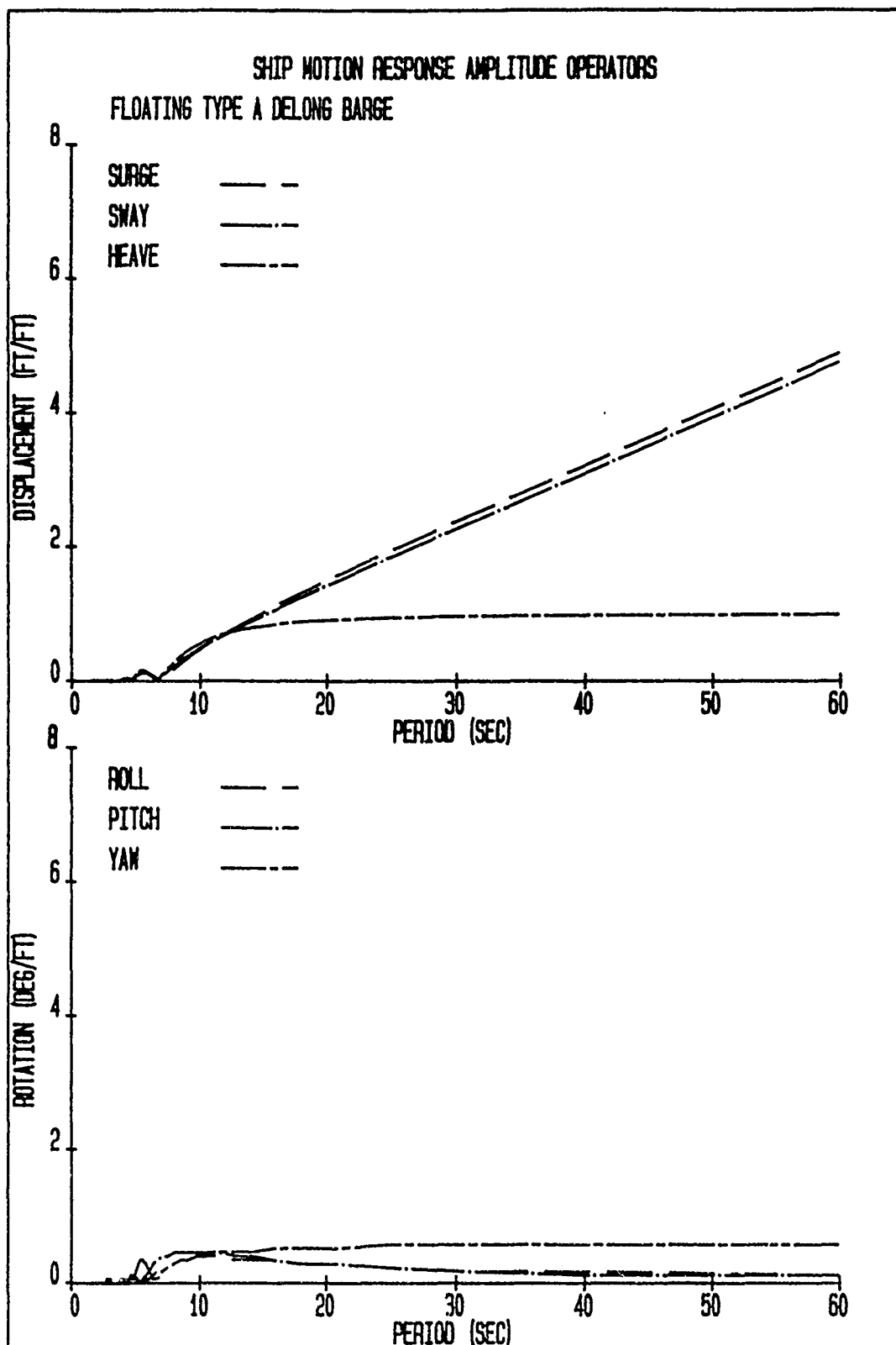
FIG. 9 - TYPICAL DE LONG TYPE A BARGE
RESPONSE AMPLITUDE OPERATORS.
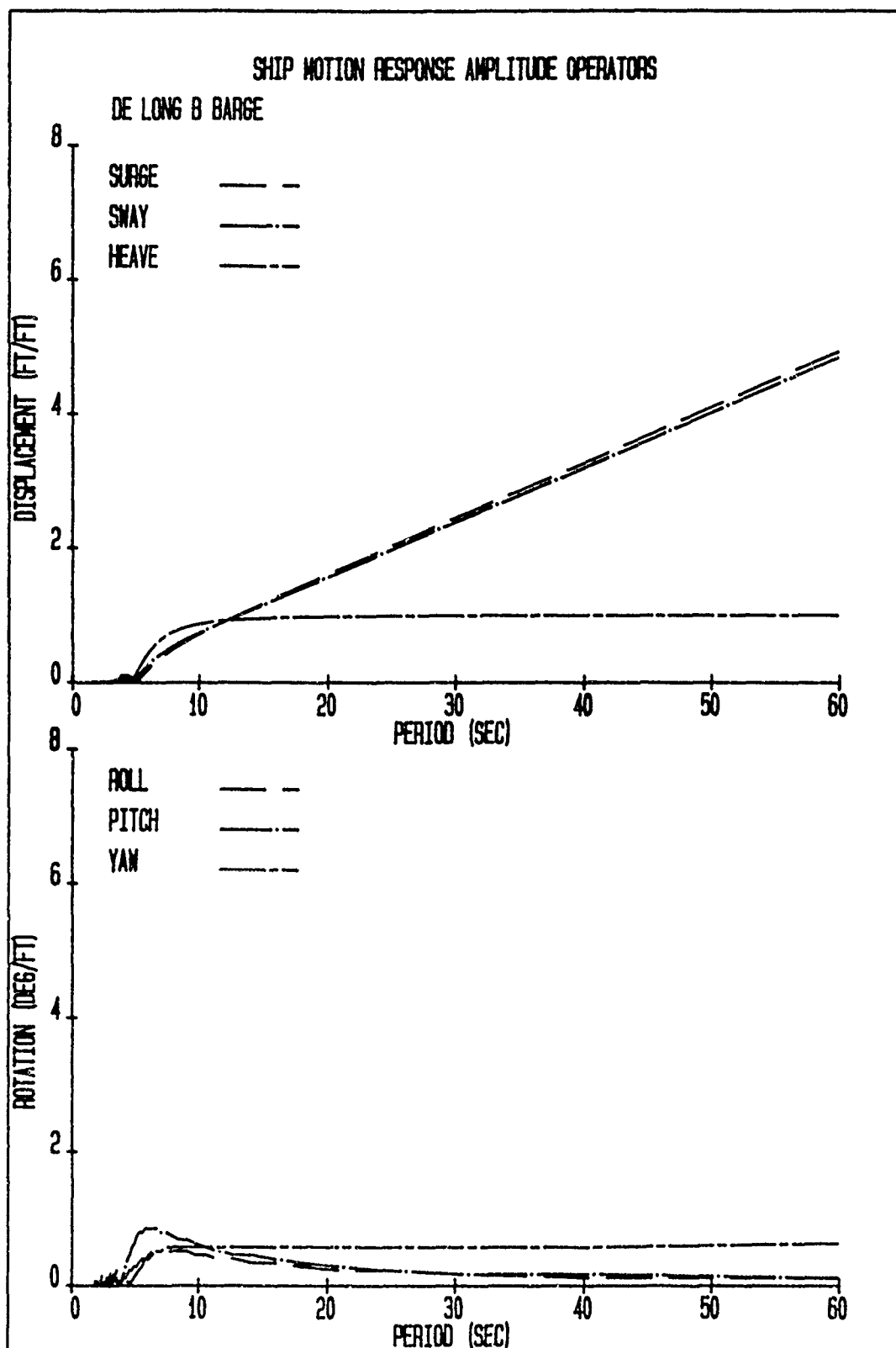
FIG. 10 - TYPICAL DE LONG TYPE B BARGE
RESPONSE AMPLITUDE OPERATORS.
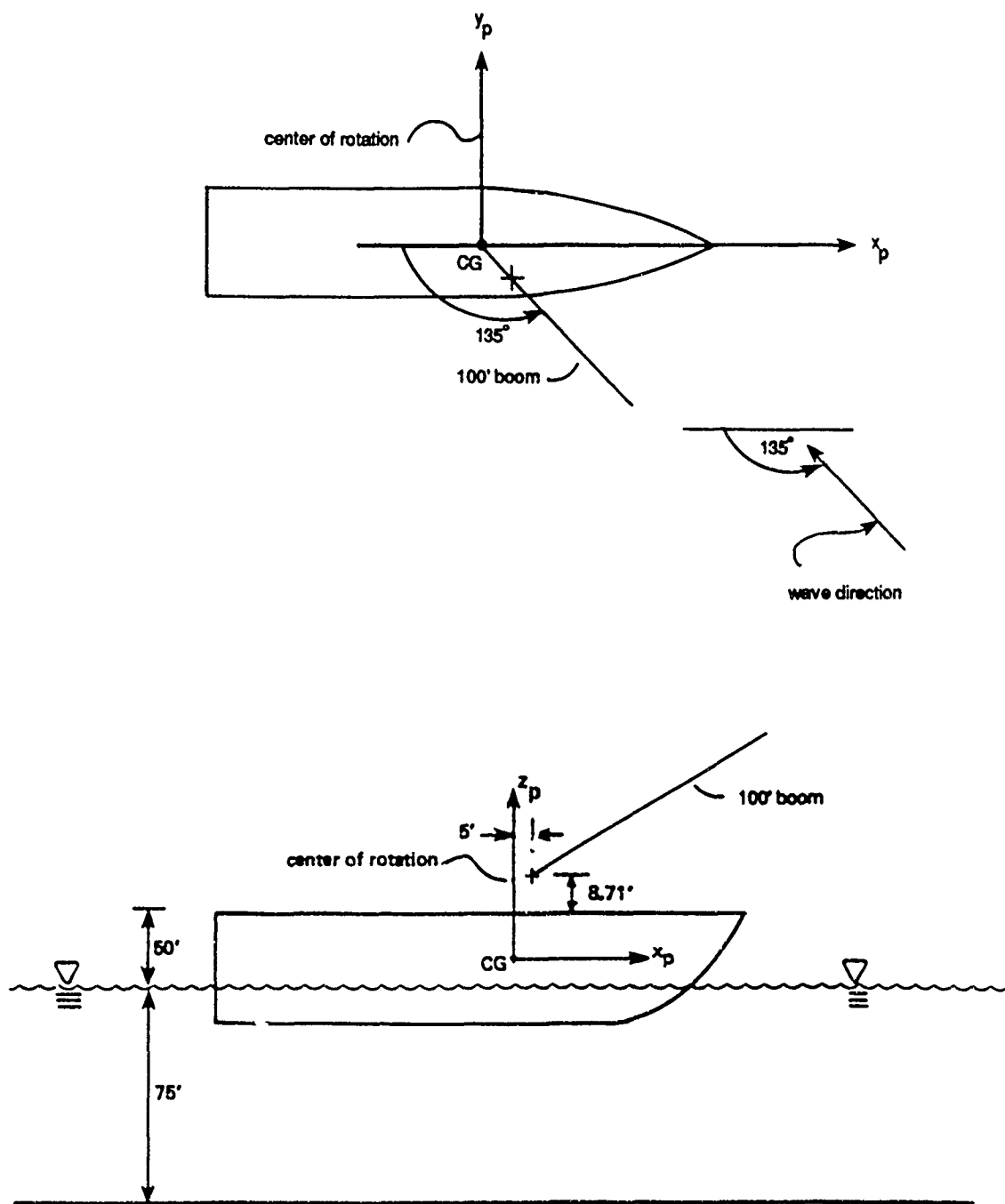
FIG. 11 - SUPPORTING PLATFORM MODEL FOR THE
EXAMPLE PROBLEM USING A C3 HULL

5.3.2 <u>Crane Geometry</u>: The crane geometry for the EXAM4000 test problem is
shonw in Figure 12. The following section property compuations
demonstrate how the crane geometry data required by Table III may be
computed and present the material properties that are used:
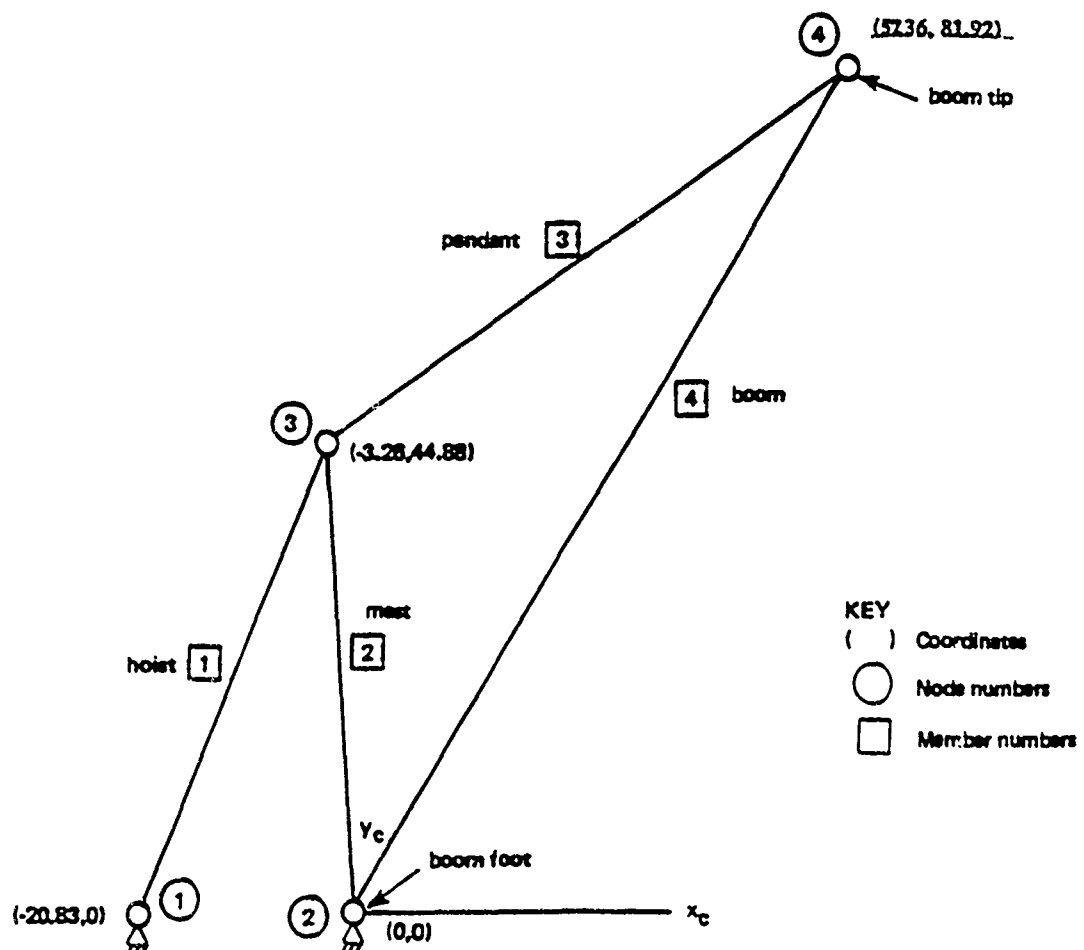
FIG. 12 - CRANE MODEL FOR THE EXAM4000 CRANE
USED IN THE EXAMPLE PROBLEM.

Boom

Single circular tube section

$d_o = 4.75$ in.
$d_i = 4.0$ in.

$r = d/2$

$r_o = 2.375$ in.
$r_i = 2.0$ in.

$A = \pi(r_o{}^2 - r_i{}^2)$

$\quad = 5.15$ in.^{2}

$I_{zz} = I_{yy} = (1/4)\pi(r_o{}^4 - r_i{}^4)$

$\quad\quad\quad = 12.42$ in.

Four circular tube chords

Height = 47 in.

$A_T = 4 (5.15)$ in.^{2}

$\boxed{A_T = 20.60 \text{ in.}^2}$

$I_1 = \bar{I} + A d^2$

$\quad = 12.42 + 20.60 (47/2)^2$

$\quad = 11{,}388.77$ in.^{4}

$I_T = 4 (11{,}388.77)$

$\boxed{I_T = 45{,}555.08 \text{ in.}^4}$

$\boxed{E = 30 \times 10^6 \text{ psi}}$

Pendants

$A = 1.59$ in.^{2}

$A_T = 4 A = 4 (1.59)$

$\boxed{A_T = 6.36 \text{ in.}^2}$

Boom Hoist Rope

$A = 0.142$ in.^{2}

$A_T = 16 A$ for 16 strands

$A_T = 16 (0.142)$

$\boxed{A_T = 2.27 \text{ in.}^2}$

The pendant and boom hoist ropes do not support bending, so the bending moment of inertia does not have meaning, however, the plane frame stiffness method of analysis requires non-zero moments of inertia. Therefore, a very small moment of inertia is used for the pendant and boom hoist member properties.

$I = 0.2$ in.^{4}

$E = 24 \times 10^6$ psi

Mast

Two rectangular tube sections

5-1/2 x 16 x 1/4

$A = 10.5$ in.^{2}

Load Hoist Rope

1-in. diam

$A = 0.582$ in.^{2}

$F_B = 103{,}400$ lb

Mast   Load Hoist Rope

$I = 325.7$ in.^{4} $E = 15 \times 10^6$ psi

$A_T = 2 (10.5)$ Hook velocity = 100 fpm

$A_T = 21.0$ in.^{2} Four parts of line

$I_T = 2 (325.7)$

$I_T = 651.4$ in.^{2}

$E = 30 \times 10^6$ psi

5.3.3 **Land Load Ratings With Sidelead**: The land crane rating chart (Table VII for the EXAM4000) input required in line type H of Table III are computed separately from the SAE J1366 rating procedure. The procedure requires the crane to be designed so it would pass SAE J987 if it were tested. This criterion establishes the 2.0% sidelead ratings. Strength margins, Section 5 of the AISC Manual of Steel Construction, are evaluated for each of the respective sideleads. Appropriate vertical load derating is required where the allowable margins are exceeded in any of the crane components. The offlead consideration in this rating at this stage is optional.

5.4   **Example Solution**: A solution for the EXAM4000 example crane supported on a C3 platform is presented in the following pages. The EXAM4000.DAT file shown in Table VIII and the C3.DAT file shown in Table VI were used to produce this s¯'ution, which is found in the EXAM4000.MOV file after the SAE J1366 has executed. The EXAM4000.DAT and the C3.DAT files are provided with the program on the distribution diskette.

TABLE VII - LAND RATING CHART FOR THE EXAM4000 CRANE

Operating Radius (ft)	Boom Point Elevation (ft)	Land Rated Load (lb) With Side Lead/Off Lead (%)						
		2.0/0	2.7/0	3.0/6	4.0/8	6.0/12	8.0/16	11.0/22
30.0	107.0	264,600	264,600	264,600	251,370	238,140	224,910	211,680
35.0	105.5	211,500	211,500	211,500	200,925	190,350	179,775	169,200
40.0	104.0	172,000	172,000	172,000	163,400	154,800	146,200	137,600
45.0	102.0	144,000	144,000	144,000	137,180	129,960	122,740	115,520
50.0	99.5	124,100	124,100	124,100	117,895	111,690	105,485	99,280
60.0	93.5	96,200	96,200	96,200	91,390	86,580	81,770	76,960
70.0	86.0	78,000	78,000	78,000	74,100	70,200	66,300	62,400
80.0	76.0	65,200	65,200	65,200	61,940	58,680	55,420	52,160
90.0	62.5	55,700	55,700	55,700	52,915	50,130	47,345	44,560
100.0	41.0	46,400	46,400	46,400	44,080	41,760	39,440	37,120

TABLE VIII - TYPICAL CRANE DATA FILE - EXAM4000.DAT
FOR THE EXAM4000 CRANE

```
                                             COLUMN
LINE        1         2         3         4         5         6         7         8
TYPE 12345678901234567890123456789012345678901234567890123456789012345678901234567890

A    THE ABC CRANE COMPANY                 EXAM4000  243093033
B        135.0      75.0      135.0     100.0
C         50.0     100.0        5.0       8.708     0.0       0.0       0.582  15.0E6
D    103400.00       4
E          4         4         10        NO
F        -20.83      0.000      1         1         0             2 GANTRY TOP
F          0.0       0.0        1         1         0             0 BOOM FOOT
F         -3.2642   44.8817     0         0         0             1 MAST TOP
F         57.3575   81.915      0         0         0             1 BOOM TIP
G           1         3          0         0         2.27      0.2    24.0  E6 HOIST
G           2         3          0         0        21.0     651.4    30.0  E6 MAST
G           3         4          0         0         6.36      0.2    24.0  E6 PENDENT
G           2         4          0         0        20.6    45555.0   30.0  E6 BOOM
H         30.0     107.0    264600.0  264600.0  251370.0  238140.0  224910.0  211680.0
H         35.0     105.5    211500.0  211500.0  200925.0  190350.0  179775.0  169200.0
H         40.0     104.0    172000.0  172000.0  163400.0  154800.0  146200.0  137600.0
H         45.0     102.0    144400.0  144400.0  137180.0  129960.0  122740.0  115520.0
H         50.0      99.5    124100.0  124100.0  117895.0  111690.0  105485.0   99280.0
H         60.0      93.5     96200.0   96200.0   91390.0   86580.0   81770.0   76960.0
H         70.0      86.0     78000.0   78000.0   74100.0   70200.0   66300.0   62400.0
H         80.0      76.0     65200.0   65200.0   61940.0   58680.0   55420.0   52160.0
H         90.0      62.5     55700.0   55700.0   52915.0   50130.0   47345.0   44560.0
H        100.0      41.0     46400.0   46400.0   44080.0   41760.0   39440.0   37120.0
```

SAE J1366 VERSION 4.0 RATINGS FOR A EXAM4000   CRANE

MANUFACTURER: THE ABC CRANE COMPANY
CRANE: EXAM4000   SERIAL NUMBER: 243093033

WAVE DIRECTION ANGLE - ZERO TO STERN, CCW	135.00	DEG
WATER DEPTH	75.00	FT
SWING ANGLE - ZERO OVER STERN, CCW	135.00	DEG
LOAD HOIST VELOCITY, POSITIVE UP	100.00	FT/MIN
STANDARDIZED VARIABLE FOR VELOCITY	1.28	
DECK ELEVATION ABOVE WATER SURFACE	50.00	FT
BOOM LENGTH	100.00	FT
CENTER OF ROTATION TO BOOM FOOT	5.00	FT
DECK TO BOOM FOOT	8.71	FT
X LOCATION OF CENTER OF ROTATION	0.00	FT
Y LOCATION OF CENTER OF ROTATION	0.00	FT
AREA OF LOAD HOIST ROPE	0.58	IN**2
MODULUS OF ELASTICITY OF LOAD HOIST ROPE	15000000.	PSI
LOAD HOIST ROPE BREAKING STRENGTH	103400.	LB
LOAD HOIST NUMBER OF PARTS OF LINE	4	
NUMBER OF MEMBERS IN CRANE MODEL	4	
NUMBER OF JOINTS IN CRANE MODEL	4	
NUMBER OF BOOM ANGLES IN RATING CHART	10	
LAND RATING INCLUDES OFF LEAD	NO	

CRANE MODEL IN THE PLANE OF THE BOOM, ORIGIN AT THE BOOM FOOT

NODE	LOCATION	COORDINATES (FT) X	Y	RESTRAINTS DX	DY	RZ	RAISE/LOWER WITH BOOM
1	GANTRY TOP	-20.83	0.00	1	1	0	2
2	BOOM FOOT	0.00	0.00	1	1	0	0
3	MAST TOP	-3.26	44.88	0	0	0	1
4	BOOM TIP	57.36	81.92	0	0	0	1

BOOM TIP NODE NUMBER IS NODE   4

MEMBER	END NODES I	J	ROTATION END RELEASE I	J	AREA (IN**2)	MOMENT OF INERTIA (IN**4)	MODULUS OF ELASTICITY (PSI)
1 HOIST	1	3	0	0	2.27	0.2	24000000.
2 MAST	2	3	0	0	21.00	651.4	30000000.
3 PENDENT	3	4	0	0	6.36	0.2	24000000.
4 BOOM	2	4	0	0	20.60	45555.0	30000000.

SAE J1366 LAND RATING CHART FOR A EXAM4000 CRANE

OPERATING RADIUS (FT)	BOOM POINT ELEVATION (FT)	STATIC RATED LOAD (LB)					
			SIDELEAD (%)				
		2.7	3.0	4.0	6.0	8.0	11.0
			OFFLEAD (%)				
		0.0	6.0	8.0	12.0	16.0	22.0
30.00	107.00	264600.	264600.	251370.	238140.	224910.	211680.
	PMAX		118171.	118171.	118171.	118171.	116218.
	4-PART WS		82720.	82720.	82720.	82720.	82720.
	1-PART WS		20680.	20680.	20680.	20680.	20680.
35.00	105.50	211500.	211500.	200925.	190350.	179775.	169200.
	PMAX		118171.	118171.	118171.	118171.	101325.
	4-PART WS		82720.	82720.	82720.	82720.	82720.
	1-PART WS		20680.	20680.	20680.	20680.	20680.
40.00	104.00	172000.	172000.	163400.	154800.	146200.	137600.
	PMAX		118171.	118171.	117516.	103133.	88113.
	4-PART WS		82720.	82720.	82720.	82720.	82720.
	1-PART WS		20680.	20680.	20680.	20680.	20680.
45.00	102.00	144400.	144400.	137180.	129960.	122740.	115520.
	PMAX		118171.	115979.	102270.	90521.	78172.
	4-PART WS		82720.	82720.	82720.	82720.	82720.
	1-PART WS		20680.	20680.	20680.	20680.	20680.
50.00	99.50	124100.	124100.	117895.	111690.	105485.	99280.
	PMAX		110898.	101835.	90565.	80757.	70404.
	4-PART WS		82720.	82720.	82720.	79312.	74647.
	1-PART WS		20680.	20680.	20680.	20680.	20680.
60.00	93.50	96200.	96200.	91390.	86580.	81770.	76960.
	PMAX		88213.	81616.	73587.	66425.	58843.
	4-PART WS		72331.	68714.	65098.	61481.	57865.
	1-PART WS		20680.	20680.	20680.	20680.	20680.
70.00	86.00	78000.	78000.	74100.	70200.	66300.	62400.
	PMAX		72937.	67879.	61875.	56411.	50644.
	4-PART WS		58647.	55714.	52782.	49850.	46917.
	1-PART WS		20680.	20680.	20680.	20680.	20680.
80.00	76.00	65200.	65200.	61940.	58680.	55420.	52160.
	PMAX		61981.	57976.	53356.	49079.	44603.
	4-PART WS		49023.	46571.	44120.	41669.	39218.
	1-PART WS		20680.	20680.	20680.	20680.	20680.
90.00	62.50	55700.	55700.	52915.	50130.	47345.	44560.
	PMAX		53759.	50526.	46926.	43539.	40050.
	4-PART WS		41880.	39786.	37692.	35598.	33504.
	1-PART WS		20680.	20680.	20680.	20680.	20680.
100.00	41.00	46400.	46400.	44080.	41760.	39440.	37120.
	PMAX		45554.	43050.	40411.	37881.	35363.
	4-PART WS		34887.	33143.	31398.	29654.	27910.
	1-PART WS		20680.	20680.	20680.	20680.	20680.

SAE J1366 DYNAMIC LOAD RATING CHART FOR A EXAM4000   CRANE

CRANE SUPPORTING PLATFORM: C3 HULL
SIGNIGICANT WAVE HEIGHT   1.00 FT
AVERAGE WAVE PERIOD   2.40 SEC
AVERAGE WAVE LENGTH   20.00 FT
WAVE INSTRUMENT READING   0.26 FT/SEC

ANGLE (DEG)	BOOM RADIUS (FT)	RATED STATIC (LB)	LOAD DYNAMIC (LB)	PER-CENT DERATE	VERTICAL STIFFNESS (LB/FT)	BOOM TIP VELOCITY (FT/MIN)	BOAT VELOCITY (FT/MIN)	BOAT ACCEL (FT/SSQ)
75.73	30.00	82720.	82720.	30.	145912.	-0.09	78.54	0.00
72.78	35.00	82720.	82720.	30.	133772.	0.00	78.54	0.00
69.83	40.00	82720.	82720.	30.	121404.	0.11	78.54	0.00
66.79	45.00	82720.	82720.	30.	109083.	0.00	78.54	0.00
63.64	50.00	82720.	82720.	25.	97042.	-0.14	78.54	0.00
57.03	60.00	72331.	66678.	24.	74968.	0.17	78.54	0.00
49.94	70.00	58647.	55907.	23.	56300.	-0.20	78.54	0.00
41.90	80.00	49023.	48453.	22.	40663.	0.23	78.54	0.00
32.33	90.00	41880.	41880.	22.	27704.	-0.26	78.54	0.00
18.77	100.00	34887.	34887.	23.	16104.	0.29	78.54	0.00

SINGLE AMPLITUDE CRANE PLATFORM MOTION STATISTICS

        SIGNIFICANT HEAVE   0.00 FT
        SIGNIFICANT PITCH   0.00 DEG
        SIGNIFICANT ROLL   0.00 DEG

SIGNIFICANT WAVE HEIGHT   0.94 FT

SAE J1366 DYNAMIC LOAD RATING CHART FOR A EXAM4000   CRANE

CRANE SUPPORTING PLATFORM: C3 HULL
SIGNIGICANT WAVE HEIGHT   2.90 FT
AVERAGE WAVE PERIOD   '..90 SEC
AVERAGE WAVE LENGTH   52.00 FT
WAVE INSTRUMENT READING   0.46 FT/SEC

ANGLE (DEG)	BOOM RADIUS (FT)	RATED STATIC (LB)	LOAD DYNAMIC (LB)	PER- CENT DERATE	VERTICAL STIFFNESS (LB/FT)	BOOM TIP VELOCITY (FT/MIN)	BOAT VELOCITY (FT/MIN)	BOAT ACCEL (FT/SSQ)
75.73	30.00	82720.	69903.	41.	146066.	-2.50	140.14	0.07
72.78	35.00	82720.	69903.	41.	133901.	-1.22	140.03	0.16
69.83	40.00	82720.	69903.	41.	121509.	0.36	140.16	0.02
66.79	45.00	82720.	69903.	40.	109167.	2.00	140.10	0.11
63.64	50.00	82720.	63175.	38.	97108.	2.89	140.16	-0.04
57.03	60.00	68714.	51217.	37.	75006.	1.86	140.12	-0.09
49.94	70.00	55714.	44019.	35.	56320.	-1.83	140.06	-0.15
41.90	80.00	46571.	39062.	33.	40673.	-3.60	140.16	0.04
32.33	90.00	39786.	35380.	30.	27709.	-0.25	139.93	0.22
18.77	100.00	33143	31811.	26.	16105.	4.01	140.03	0.16

SINGLE AMPLITUDE CRANE PLATFORM MOTION STATISTICS

       SIGNIFICANT HEAVE   0.08 FT
       SIGNIFICANT PITCH   0.05 DEG
       SIGNIFICANT ROLL   0.09 DEG

SIGNIFICANT WAVE HEIGHT   2.87 FT

SAE J1366 DYNAMIC LOAD RATING CHART FOR A EXAM4000   CRANE

CRANE SUPPORTING PLATFORM: C3 HULL
SIGNIGICANT WAVE HEIGHT   6.90 FT
AVERAGE WAVE PERIOD   5.40 SEC
AVERAGE WAVE LENGTH   99.00 FT
WAVE INSTRUMENT READING   0.79 FT/SEC

ANGLE (DEG)	BOOM RADIUS (FT)	RATED STATIC (LB)	LOAD DYNAMIC (LB)	PER- CENT DERATE	VERTICAL STIFFNESS (LB/FT)	BOOM TIP VELOCITY (FT/MIN)	BOAT VELOCITY (FT/MIN)	BOAT ACCEL (FT/SSQ)
75.73	30.00	82720.	52040.	56.	146505.	-5.51	238.34	-0.67
72.78	35.00	82720.	52040.	56.	134267.	-16.64	239.99	-0.40
69.83	40.00	82720.	52040.	56.	121808.	-25.26	239.92	-0.41
66.79	45.00	82720.	51122.	50.	109405.	-32.91	240.76	-0.13
63.64	50.00	82720.	45670.	50.	97294.	-36.43	240.74	0.15
57.03	60.00	65098.	37083.	50.	75113.	-27.70	238.14	0.70
49.94	70.00	52782.	30466.	51.	56378.	-2.80	235.72	0.96
41.90	80.00	44120.	25939.	51.	40702.	26.16	236.03	0.93
32.33	90.00	37692.	23528.	50.	27720.	48.10	238.78	0.61
18.77	100.00	31398.	22378.	45.	16109.	57.51	240.86	0.00

SINGLE AMPLITUDE CRANE PLATFORM MOTION STATISTICS

        SIGNIFICANT HEAVE   0.62 FT
        SIGNIFICANT PITCH   0.53 DEG
        SIGNIFICANT ROLL   0.79 DEG

SIGNIFICANT WAVE HEIGHT   6.74 FT

SAE J1366 DYNAMIC LOAD RATING CHART FOR A EXAM4000   CRANE

CRANE SUPPORTING PLATFORM: C3 HULL
SIGNIGICANT WAVE HEIGHT   13.00 FT
AVERAGE WAVE PERIOD   7.00 SEC
AVERAGE WAVE LENGTH   164.00 FT
WAVE INSTRUMENT READING   1.15 FT/SEC

ANGLE (DEG)	BOOM RADIUS (FT)	RATED STATIC (LB)	LOAD DYNAMIC (LB)	PER-CENT DERATE	VERTICAL STIFFNESS (LB/FT)	BOOM TIP VELOCITY (FT/MIN)	BOAT VELOCITY (FT/MIN)	BOAT ACCEL (FT/SSQ)
75.73	30.00	82720.	32060.	73.	147116.	59.27	342.60	-1.08
72.78	35.00	82720.	32060.	73.	134775.	53.36	337.12	-1.41
69.83	40.00	82720.	30938.	70.	122223.	44.45	330.18	-1.74
66.79	45.00	82720.	28347.	69.	109736.	32.59	321.80	-2.06
63.64	50.00	79312.	27068.	66.	97552.	8.89	321.38	-2.08
57.03	60.00	61481.	27088.	59.	75261.	-40.57	311.05	-2.40
49.94	70.00	49850.	27088.	52.	56458.	-117.82	319.65	-2.13
41.90	80.00	41669.	27088.	45.	40741.	-203.35	347.88	-0.58
32.33	90.00	35598.	27088.	38.	27737.	-157.00	305.46	2.56
18.77	100.00	29654.	23433.	38.	16114.	-15.83	239.25	3.82

SINGLE AMPLITUDE CRANE PLATFORM MOTION STATISTICS

        SIGNIFICANT HEAVE   1.82 FT
        SIGNIFICANT PITCH   2.00 DEG
        SIGNIFICANT ROLL   5.63 DEG

SIGNIFICANT WAVE HEIGHT   12.38 FT

SAE J1366 DYNAMIC LOAD RATING CHART FOR A EXAM4000   CRANE

CRANE SUPPORTING PLATFORM: C3 HULL
SIGNIGICANT WAVE HEIGHT   23.00 FT
AVERAGE WAVE PERIOD   8.70 SEC
AVERAGE WAVE LENGTH   258.00 FT
WAVE INSTRUMENT READING   1.64 FT/SEC

ANGLE (DEG)	BOOM RADIUS (FT)	RATED STATIC (LB)	LOAD DYNAMIC (LB)	PER-CENT DERATE	VERTICAL STIFFNESS (LB/FT)	BOOM TIP VELOCITY (FT/MIN)	BOAT VELOCITY (FT/MIN)	BOAT ACCEL (FT/SSQ)
75.73	30.00	82720.	16355.	86.	148344.	179.82	485.43	-1.36
72.78	35.00	82720.	13558.	87.	135797.	193.43	477.95	-1.70
69.83	40.00	82720.	11362.	87.	123055.	205.00	468.82	-2.03
66.79	45.00	82720.	10018.	87.	110399.	214.65	458.06	-2.36
63.64	50.00	74647.	9219.	87.	98068.	222.04	445.70	-2.68
57.03	60.00	57865.	8630.	85.	75558.	227.99	416.40	-3.30
49.94	70.00	46917.	8630.	83.	56617.	241.74	360.42	-4.14
41.90	80.00	39218.	8630.	81.	40818.	249.78	292.71	-4.85
32.33	90.00	33504.	8630.	78.	27770.	251.20	215.46	-5.41
18.77	100.00	27910.	8630.	76.	16123.	30^.51	69.91	-5.94

SINGLE AMPLITUDE CRANE PLATFORM MOTION STATISTICS

              SIGNIFICANT HEAVE   4.60 FT
              SIGNIFICANT PITCH   4.40 DEG
              SIGNIFICANT ROLL   16.69 DEG

SIGNIFICANT WAVE HEIGHT   21.58 FT

SAE J1366 CRANE RATING CHART FOR A CRANE MOUNTED ON A FLOATING PLATFORM

MANUFACTURER: THE ABC CRANE COMPANY
CRANE MODEL: EXAM4000   SERIAL NUMBER: 243093033 BOOM LENGTH 100.00 FT

CRANE SUPPORTING PLATFORM: C3 HULL
DISTANCE FROM PLATFORM DECK TO SEA LEVEL   50.00 FT
CRANE LOCATION: DISTANCE FROM STERN TO CENTER OF ROTATION   0.00 FT
                DISTANCE FROM PORT SIDE TO CENTER OF ROTATION   0.00 FT
                DISTANCE FROM PLATFORM DECK TO BOOM FOOT   8.71 FT

BOOM RADIUS (FT)	BOOM ANGLE (DEG)	STATIC RATING (LB)	DYNAMIC RATINGS (LB) AT THE FOLLOWING WAVE INSTRUMENT READINGS, HBAR/TBAR (FT/SEC)				
			0.26	0.46	0.79	1.15	1.64

4-PART MAIN HOIST LINE

BOOM RADIUS (FT)	BOOM ANGLE (DEG)	STATIC RATING (LB)	0.26	0.46	0.79	1.15	1.64
30.0	75.7	82720.	82720.	69903.	52040.	32060.	16355.
35.0	72.8	82720.	82720.	69903.	52040.	32060.	13558.
40.0	69.8	82720.	82720.	69903.	52040.	30938.	11362.
45.0	66.8	82720.	82720.	69903.	51122.	28347.	10018.
50.0	63.6	82720.	82720.	63175.	45670.	27088.	9219.
60.0	57.0	72331.	66678.	51217.	37083.	27088.	8630.
70.0	49.9	58647.	55907.	44010.	30466.	27088.	8630.
80.0	41.9	49023.	48453.	39062.	25939.	27088.	8630.
90.0	32.3	41880.	41880.	35380.	23528.	27088.	8630.
100.0	18.8	34887.	34887.	31811.	22378.	23433.	8630.

1-PART WHIP HOIST LINE

BOOM RADIUS (FT)	BOOM ANGLE (DEG)	STATIC RATING (LB)	0.26	0.46	0.79	1.15	1.64
30.0	75.7	20680.	20680.	20680.	20680.	20680.	16355.
35.0	72.8	20680.	20680.	20680.	20680.	20680.	13558.
40.0	69.8	20680.	20680.	20680.	20680.	20680.	11362.
45.0	66.8	20680.	20680.	20680.	20680.	20680.	10018.
50.0	63.6	20680.	20680.	20680.	20680.	20680.	9219.
60.0	57.0	20680.	20680.	20680.	20680.	20680.	8630.
70.0	49.9	20680.	20680.	20680.	20680.	20680.	8630.
80.0	41.9	20680.	20680.	20680.	20680.	20680.	8630.
90.0	32.3	20680.	20680.	20680.	20680.	20680.	8630.
100.0	18.8	20680.	20680.	20680.	20680.	20680.	8630.

APPENDIX C

PROGRAM J1366 LISTING

```
      PROGRAM J1366
C
C     DYNAMIC RATING OF MARINE CRANES    SAE J1366 VERSION 4.0
C
      CHARACTER * 40 NODEID(50), MEMBID(50)*19, CRANE*20, NAMSHP,
     $         MANFAC, SERIAL*10, SHIPFL*20
      CHARACTER ITYPE*1, EXT*4, LEDOFF*3
      INTEGER XRST(50), YRST(50), ZRST(50), BTNODE
      REAL IZ, KN, LINSPD
      DIMENSION X(50), Y(50), BRAD(20), BPELV(20), PMAX(20,5)
      DIMENSION DD(101), VD(101), AD(101), WD(20), ICOR(50), WCOS(101)
      DIMENSION JJ(50), JK(50), AR(50), IZ(50), E(50), W(150), D(150),
     $         XBASE(50), YBASE(50), JMER(50), KMER(50), OFFLED(6)
      DIMENSION H13A(5), TBARA(5), WAVLNA(5), WINSTR(5), DYNLDM(20,5),
     $         DYNLDS(20,5), BANGD(20), STATLD(20,5), SPRTLD(20,5),
     $         PLAND(20,5), SLAND(20), SIDLED(6)
      COMMON DZ(80), PHI(80), THE(80), AZ(80), APHI(80), ATHE(80),
     $         WN(80),  KN(80)
      COMMON /OUTPUT/ SIGHEV, SIGPCH, SIGROL, SIGWAV
      DATA W / 150*0.0 /, ZRST /50*1/, WD /20*1.0E7/
      DATA H13A / 1.0, 2.9, 6.9, 13.0, 23.0 /,
     $     TBARA / 2.4, 3.9, 5.4, 7.0, 8.7 /,
     $     WAVLNA / 20.0, 52.0, 99.0, 164.0, 258.0 /,
     $     OFFLED / 0.0, 6.0, 8.0, 12.0, 16.0, 22.0 /,
     $     SIDLED / 2.7, 3.0, 4.0,  6.0,  8.0, 11.0 /
C
C     OPEN DATA FILES
C       IRED1 IS THE DISK DIRVE FOR THE CRANE DATA FILE
C       IRED2 IS THE DISK DRIVE FOR THE SHIP RAO FILE
C       IRED3 IS THE KEYBOARD
C       IWRT1 IS THE CRANE OUTPUT FILE OR LINE PRINTER
C       IWRT3 IS THE DISPLAY
C
      IRED1 = 7
      IRED2 = 8
      IRED3 = 1
      IWRT1 = 6
      IWRT3 = 2
      OPEN(IRED3, FILE = 'CON')
      OPEN(IWRT3, FILE = 'CON')
      WRITE(IWRT3,'('' <NAME OF CRANE DATA FILE> '')')
```

```
        READ(IRED3,'(A20)') CRANE
        WRITE(IWRT3,'('' <TYPE OF RATING, FIXED OR MOVING PLATFORM> '')')
        READ(IRED3,'(A)') ITYPE
        NCHR = INDEX(CRANE,' ') - 1
        OPEN(IRED1, FILE=CRANE(1:NCHR)//'.DAT',STATUS='OLD')
        EXT = 'ERR'
        IF(ITYPE .EQ. 'M' .OR. ITYPE .EQ. 'm') EXT = 'MOV'
        IF(ITYPE .EQ. 'F' .OR. ITYPE .EQ. 'f') EXT = 'FIX'
        OPEN(IWRT1, FILE=CRANE(1:NCHR)//'.'//EXT,STATUS='UNKNOWN')
        IF(ITYPE .EQ. 'M' .OR. ITYPE .EQ. 'm') THEN
        WRITE(IWRT3,'('' <NAME OF SHIP RAO DATA FILE> '')')
        READ(IRED3, '(A20)') SHIPFL
        NCHR2 = INDEX(SHIPFL, ' ') - 1
        OPEN(IRED2, FILE=SHIPFL(1:NCHR2)//'.RAO', STATUS='UNKNOWN')
        END IF
        G = 32.2
        NUMSIM = 101
        NUMSEA = 5
        WRITE(IWRT1,532) CRANE(1:10)
 532    FORMAT('1SAE J1366 VERSION 4.0 RATINGS FOR A ', A10, ' CRANE'/)
C
C       READ PROBLEM PARAMETERS
C
        READ(IRED1,527) MANFAC, CRANE, SERIAL, BETA, DEPTH, ALPHA,
     $          LINSPD
 527    FORMAT(A40, A10, A10/, 4F10.0)
        SV = 1.28
        WRITE(IWRT1,502) MANFAC, CRANE, SERIAL, BETA, DEPTH, ALPHA,
     $          LINSPD, SV
 502    FORMAT(' MANUFACTURER: ',A40,/
     $  ' CRANE: ', A10,' SERIAL NUMBER: ', A10 /,
     $  ' WAVE DIRECTION ANGLE - ZERO TO STERN, CCW ', F10.2, ' DEG'/
     $  ' WATER DEPTH                              ', 6X, F10.2, ' FT'/
     $  ' SWING ANGLE - ZERO OVER STERN, CCW ', 7X, F10.2, ' DEG'/
     $  ' LOAD HOIST VELOCITY, POSITIVE UP   ', 6X, F10.2, ' FT/MIN'/
     $  ' STANDARDIZED VARIABLE FOR VELOCITY ', 6X, F10.2)
        READ(IRED1,540) DKELV, BL, CRBF, DKBF, CRX, CRY, AROPE, EROPE,
     $          BRKSTR, NUMPRT
 540    FORMAT(8F10.0/F10.0, I10, F10.0)
        WRITE(IWRT1,650) DKELV, BL, CRBF, DKBF, CRX, CRY, AROPE, EROPE,
     $          BRKSTR, NUMPRT
 650    FORMAT(' DECK ELEVATION ABOVE WATER SURFACE        ', F10.2,' FT'/
     $  ' BOOM LENGTH                               ', F10.2, ' FT'/
     $  ' CENTER OF ROTATION TO BOOM FOOT           ', F10.2, ' FT'/
     $  ' DECK TO BOOM FOOT                         ', F10.2, ' FT'/
     $  ' X LOCATION OF CENTER OF ROTATION          ', F10.2, ' FT'/
     $  ' Y LOCATION OF CENTER OF ROTATION          ', F10.2, ' FT'/
     $  ' AREA OF LOAD HOIST ROPE                   ', F10.2, ' IN**2'/
     $  ' MODULUS OF ELASTICITY OF LOAD HOIST ROPE  ', F10.0, ' PSI'/
     $  ' LOAD HOIST ROPE BREAKING STRENGTH         ', F10.0, ' LB'/
     $  ' LOAD HOIST NUMBER OF PARTS OF LINE        ', I10 )
C
C       READ CRANE GEOMETRY
```

```
C
      READ(IRED1,526) NM, NJ, NUMRAD, LEDOFF
 526  FORMAT(3I10, 7X, A)
      WRITE(IWRT1,506) NM, NJ, NUMRAD, LEDOFF
 506  FORMAT( ' NUMBER OF MEMBERS IN CRANE MODEL       ', 10X, I5 /
     $        ' NUMBER OF JOINTS IN CRANE MODEL        ', 10X, I5 /
     $        ' NUMBER OF BOOM ANGLES IN RATING CHART  ', 8X, I5 /
     $        ' LAND RATING INCLUDES OFF LEAD          ', 11X, A)
      WRITE(IWRT1,503)
 503  FORMAT(/' CRANE MODEL IN THE PLANE OF THE BOOM, ORIGIN AT',
     $       ' THE BOOM FOOT' //
     $       2X, 'NODE', 4X, 'LOCATION', 16X, 'COORDINATES (FT)',
     $       5X, 'RESTRAINTS', 4X, 'RAISE/LOWER'/
     $       37X, 'X', 9X, 'Y', 6X, 'DX', 3X, 'DY', 3X, 'RZ',
     $       3X, 'WITH BOOM'/)
C
C     NODES, NODE RESTRAINTS, BOOM NODE ROTATION, AND NODE
C     IDENTIFICATION
C
      NB1 = 0
      NB2 = 0
      IBLOCK = 0
      DO 10 I = 1, NJ
      READ(IRED1,500) X(I),Y(I),XRST(I),YRST(I),ZRST(I),ICOR(I),
     $         NODEID(I)
 500  FORMAT(2F10.0, 4I10, A20)
      WRITE(IWRT1,501) I, NODEID(I), X(I), Y(I), XRST(I), YRST(I),
     $         ZRST(I), ICOR(I)
 501  FORMAT(I5, 5X, A20, 2F10.2, 3I5, 5X, I5)
      X(I) = X(I) * 12.0
      Y(I) = Y(I) * 12.0
      IF(ICOR(I) .EQ. 3) THEN
              NB1 = I
              IBLOCK = 1
              END IF
      IF(ICOR(I) .EQ. 2) NB2 = I
 10   CONTINUE
C
C     DETERMINE THE BOOM ANGLE AND LOWER THE BOOM TO ZERO DEGREES
C             THE AXIS ORIGIN IS ASSUMED AT THE BOOM FOOT.
C             ICOR = 1 SIGNIFIES THE COORDINATE WILL ROTATE WITH THE BOOM.
C             ICOR = 2 SIGNIFIES THE COORDINATE OF THE GANTRY TOP
C             ICOR = 3 SIGNIFIES THE FLOATING HARNESS COORDINATE
C             THE BOOM TIP IS THE LAST (NJ) NODE.
C
C             IBLOCK = 1 SIGNIFIES THE CRANE HAS A FLOATING HARNESS
C
      BANG = ATAN(Y(NJ)/X(NJ))
      DO 12 I = 1, NJ
      XBASE(I) = X(I)
      YBASE(I) = Y(I)
      IF(ICOR(I) .EQ. 1) THEN
              XBASE(I) = X(I) * COS(-BANG) - Y(I) * SIN(-BANG)
```

```
                        YBASE(I) = X(I) * SIN(-BANG) + Y(I) * COS(-BANG)
                        END IF
     12    CONTINUE
           IF(IBLOCK .EQ. 1) THEN
                        PLEN  = SQRT((X(NJ) - X(NB1))**2 + (Y(NJ) - Y(NB1))**2)
                        GTLEN = SQRT((XBASE(NJ) - XBASE(NB2))**2 +
          $                          (YBASE(NJ) - YBASE(NB2))**2)
                        BHLEN = GTLEN - PLEN
                        XBASE(NB1) = (XBASE(NJ) - XBASE(NB2)) * BHLEN / GTLEN +
          $                          XBASE(NB2)
                        YBASE(NB1) = (YBASE(NJ) - YBASE(NB2)) * BHLEN / GTLEN +
          $                          YBASE(NB2)
                        IF(BHLEN .LE. 0.0) WRITE(IWRT3,
          $             '( 10X, ''<FLOATING HARNESS HAS HIT GANTRY TOP>'')')
                        END IF
           BTNODE = NJ
           WRITE(IWRT1,513) BTNODE
    513    FORMAT(/ 3X, 'BOOM TIP NODE NUMBER IS NODE ', I5, //
          $    4X, 'MEMBER', 17X, 'END', 5X, 'ROTATION',
          $    7X, 'AREA', 5X, 'MOMENT OF', 2X, 'MODULUS OF' /
          $    26X, 'NODES', 3X, 'END RELEASE', 4X, '(IN**2)',
          $    4X, 'INERTIA', 3X, 'ELASTICITY' /
          $    25X, 'I', 4X, 'J', 6X, 'I', 4X, 'J', 17X, '(IN**4)', 5X,
          $    '(PSI)' /)
    C
    C     CRANE MEMBERS AND MEMBER PROPERTIES
    C
           DO 15 I = 1, NM
           READ(IRED1,504) JJ(I), JK(I), JMER(I), KMER(I), AR(I), IZ(I),
          $ E(I), MEMBID(I)
    504    FORMAT(4I10, 2F10.2, E10.0, 1X, A10)
           WRITE(IWRT1,514) I, MEMBID(I), JJ(I), JK(I), JMER(I), KMER(I),
          $ AR(I), IZ(I), E(I)
    514    FORMAT(2X, I2, 1X, A19, I2, 3X, I2, 5X, I2, 3X, I2, 4X, F9.2,
          $ 1X, F11.1, F11.0)
     15    CONTINUE
           IDOF = 3 * NJ - 1
           W(IDOF) = - 10000.0
    C
    C     READ LAND RATING CHART
    C
           WRITE(IWRT1,516) CRANE(1:10)
    516    FORMAT('1SAE J1366 LAND RATING CHART FOR A ', A10, 'CRANE'//
          $      1X, 'OPERATING', 2X, 'BOOM POINT', 10X, 'STATIC RATED LOAD',
          $      ' (LB)', /
          $      2X, 'RADIUS', 4X, 'ELEVATION', 27X, 'SIDELEAD (%)')
           WRITE(IWRT1,517) (SIDLED(J), J = 1, 6), (OFFLED(J), J = 1, 6)
    517    FORMAT(5X,'(FT)',6X,'(FT)', 6F10.1 /, 48X, 'OFFLEAD (%)',/
          $      19X, 6F10.1/ )
           PART = FLOAT(NUMPRT)
           LINSPD = LINSPD / (60.0 * PART)
           PROPE = PART * BRKSTR / 3.5
    C
```

```
C       CRANE LAND RATING CHART MODIFIED FOR OUT OF PLANE LOADS FOR EACH
C       SEASTATE SIDELEAD AND FURTHER MODIFIED FOR OFFLEAD IN EACH SEA
C       STATE.
C
        DO 20 I = 1, NUMRAD
        READ(IRED1,528) BRAD(I), BPELV(I), SLAND(I), (PLAND(I,J), J = 1,
     $           NUMSEA)
 528    FORMAT(8F10.0)
        RAD = BRAD(I) - CRBF
        HIGHT = BPELV(I) - DKBF
        BANG = ATAN(HIGHT/RAD)
        DO 19 J = 1, NUMSEA
        AOFF = ATAN(OFFLED(J+1)/100.0)
        IF(LEDOFF .NE. 'YES') THEN
        POFF = PLAND(I,J) * COS(BANG) / COS(BANG-AOFF)
        ELSE
        POFF = 1.0E20
        END IF
        PMAX(I,J) = AMIN1(PLAND(I,J), POFF, PART * BRKSTR / 3.5)
        STATLD(I,J) = AMIN1(PLAND(I,J)/1.33, PART*BRKSTR/5.0)
        SPRTLD(I,J) = AMIN1(PLAND(I,J)/1.33,      BRKSTR/5.0)
 19     CONTINUE
        WRITE(IWRT1,522) BRAD(I), BPELV(I), SLAND(I),
     $           (PLAND(I,J), J = 1, NUMSEA), (PMAX(I,J), J = 1, NUMSEA),
     $           NUMPRT, (STATLD(I,J), J = 1, NUMSEA),
     $           (SPRTLD(I,J), J = 1, NUMSEA)
 522    FORMAT(F10.2, F10.2, 6F10.0/,
     $           20X, 'PMAX      ', 5F10.0/,
     $           19X, I2, '-PART WS ', 5F10.0/,
     $           20X, '1-PART WS ', 5F10.0/)
 20     CONTINUE
        IF(ITYPE .EQ. 'M' .OR. ITYPE .EQ. 'm') THEN
C
C       READ SHIP MOTION RESPONSE AMPLITUDE OPERATORS
C
        READ(IRED2,509) FRQMIN, FRQMAX, NUMFRQ, NAMSHP
 509    FORMAT(2F10.0, I10, 10X, A40)
        DO 21 N = 1, NUMFRQ
        READ(IRED2,510) DZ(N), PHI(N), THE(N), AZ(N), APHI(N), ATHE(N)
 510    FORMAT(6F10.0)
 21     CONTINUE
        CLOSE(IRED2)
        ELSE
        FRQMIN = 0.1050
        FRQMAX = 4.0
        NUMFRQ = 80
        NAMSHP = 'FIXED PLATFORM'
         DO 700 I = 1, NUMFRQ
         DZ(I) = 0.0
         PHI(I) = 0.0
         THE(I) = 0.0
         AZ(I) = 0.0
         APHI(I) = 0.0
```

```
          ATHE(I) = 0.0
  700   CONTINUE
        END IF
        CALL FREQ(DEPTH,FRQMIN,FRQMAX,WN,KN,NUMFRQ,IWRT1)

        DO 800 NSEA = 1, NUMSEA
        H13 = H13A(NSEA)
        TBAR = TBARA(NSEA)
        WAVLEN = WAVLNA(NSEA)
        WINSTR(NSEA) = 0.62 * H13 / TBAR
C
C     FOR EACH BOOM RADIUS, PMAX, CALCULATE WD
C
        WRITE(IWRT1,530) CRANE(1:10), NAMSHP, H13, TBAR, WAVLEN,
      $         WINSTR(NSEA)
  530   FORMAT('1SAE J1366 DYNAMIC LOAD RATING CHART FOR A ', A10,
      $ ' CRANE' //
      $ ' CRANE SUPPORTING PLATFORM: ', A40/
      $ ' SIGNIGICANT WAVE HEIGHT    ', F10.2, ' FT'/
      $ ' AVERAGE WAVE PERIOD        ', F10.2, ' SEC'/
      $ ' AVERAGE WAVE LENGTH        ', F10.2, ' FT'/
      $ ' WAVE INSTRUMENT READING    ', F10.2, ' FT/SEC'//,
      $ 11X, 'BOOM', 8X, 'RATED LOAD', 5X, 'PER- VERTICAL BOOM TIP',
      $ 3X, 'BOAT', 5X, 'BOAT'/, 3X, 'ANGLE  RADIUS     STATIC   DYNAMIC',
      $ ' CENT  STIFFNESS VELOCITY VELOCITY ACCE' /, 3X, '(DEG)', 3X,
      $ '(FT)', 6X, '(LB)', 6X, '(LB) DERATE (LB FT) (FT/MIN)',
      $ ' (FT/MIN) (FT/SSQ)'/)
        ALPHR = (180.0 - ALPHA) * 3.14159 / 180.0
C
C     RAISE THE BOOM FOR EACH BOOM ANGLE
C
        DO 35 I = 1, NUMRAD
        RAD = BRAD(I) - CRBF
        HIGHT = BPELV(I) - DKBF
        BANG = ATAN(HIGHT/RAD)
        BANGD(I) = BANG * 180.0 / 3.14159
C
C     COMPUTE THE COORDINATES RAISED WITH THE BOOM
C
        DO 23 J = 1, NJ
        X(J) = XBASE(J)
        Y(J) = YBASE(J)
        IF(ICOR(J) .EQ. 1) THEN
                TEMX = XBASE(J) * COS(BANG) - YBASE(J) * SIN(BANG)
                Y(J) = XBASE(J) * SIN(BANG) + YBASE(J) * COS(BANG)
                X(J) = TEMX
                END IF
        IF(IBLOCK .EQ. 1) THEN
                GTLEN = SQRT((X(NJ) - X(NB2))**2 + (Y(NJ) - Y(NB2))**2)
                BHLEN = GTLEN - PLEN
                X(NB1) = (X(NJ) - X(NB2)) * BHLEN / GTLEN + X(NB2)
                Y(NB1) = (Y(NJ) - Y(NB2)) * BHLEN / GTLEN + Y(NB2)
                IF(BHLEN .LE. 0.0) WRITE(IWRT3,
```

```
       $            '( 10X, ''<FLOATING HARNESS HAS HIT GANTRY TOP>'')')
                    END IF
 23    CONTINUE
C
C      LOCATE THE POINT OF INTEREST UNDER THE BOOM POINT
C
       RX = BRAD(I) * COS(ALPHR) + CRX
       RY = BRAD(I) * SIN(ALPHR) + CRY
       R = SQRT(RX*RX + RY*RY)
       ALPH2 = 180.0 - (ATAN2(RY,RX) * 180.0 / 3.14159)
C
C      CALCULATE THE WORK BOAT VELOCITY AND ACCELERATION
C
       CALL BOAT(TBAR,H13,BETA,R,ALPH2,WAVLEN,DD,VD,AD,WCOS,NUMSIM)
C
C      CALCULATE THE VERTICAL STIFFNESS
C
       AOFF = ATAN(OFFLED(NSEA+1)/100.0)
       DHOOK = 12.0 * W(IDOF) * (BL + PART * ( BPELV(I) + DKELV))
      $        / (PART**2 * AROPE * EROPE)
       CALL FRAME(NM,NJ,X,Y,XRST,YRST,ZRST,JMER,KMER,JJ,JK,AR,IZ,E,W,D)
       DTOTAL = D(IDOF) + DHOOK * COS(AOFF)
       S = W(IDOF) / DTOTAL * 12.0
C
C      CALCULATE THE BOOM POINT VELOCITY
C
       CRBT = CRBF + BL * COS(BANG)
       PIX = CRX + CRBT * COS(ALPHR)
       PIY = CRY + CRBT * SIN(ALPHR)
       CALL BPVEL(PIX,PIY,H13,TBAR,DEPTH,BETA,SV,BPV,NUMFRQ)
C
C      CALCULATE THE DYNAMIC RATED LOAD, WD
C
       WD(I) = 1.0E38
       KEY = NUMSIM
       DO 30 J = 1, NUMSIM
C
C      CALCULATE THE VELOCITY OF THE HOOK
C
       VH = BPV * WCOS(J) + LINSPD
C
C      SOLVE THE QUADRATIC EQUATION FOR WD
C
       A = PMAX(I,NSEA) ** 2
       B = - 2.0 * PMAX(I,NSEA) - S * (VD(J) + VH) ** 2 / G
       C = 1.0 - (AD(J) / G) ** 2
       DISCRM = B ** 2 - 4.0 * A * C
       TWOA = 2.0 * A
       IF(DISCRM) 25, 27, 26
 25    BR = - B / TWOA
       BI = 1.0 / TWOA
       GO TO 30
 26    SQROOT = SQRT(DISCRM)
```

```
         WD1 = (-B + SQROOT) / TWOA
         WD2 = (-B - SQROOT) / TWOA
         WD1 = 1.0 / WD1
         WD2 = 1.0 / WD2
         WD1 = AMIN1(WD1,WD2)
         GO TO 29
  27     WD1 = - B / TWOA
         WD1 = 1.0 / WD1
         WD2 = WD1
  29     IF(WD1 .LT. WD(I)) THEN
         WD(I) = WD1
         KEY = J
         END IF
  30     CONTINUE
C
C        PREPARE SINGLE AND MULTI PART RATINGS
C
         DYNLDM(I,NSEA) = AMIN1(WD(I), STATLD(I,NSEA))
         DYNLDS(I,NSEA) = AMIN1(WD(I), SPRTLD(I,NSEA))
         IF(I .GT. 1) THEN
         DYNLDM(I,NSEA) = AMIN1(DYNLDM(I,NSEA), DYNLDM(I-1,NSEA))
         DYNLDS(I,NSEA) = AMIN1(DYNLDS(I,NSEA), DYNLDS(I-1,NSEA))
         ELSE
         END IF
         RAT1 = DYNLDM(I,NSEA) / PMAX(I,NSEA) * 100.0
         RAT2 = 100.0 - RAT1
         BPVSIM = BPV * WCOS(KEY) * 60.0
         VDSIM = VD(KEY) * 60.0
         WRITE(IWRT1,524) BANGD(I), BRAD(I), STATLD(I,NSEA),
       $            DYNLDM(I,NSEA), RAT2, S, BPVSIM, VDSIM, AD(KEY)
  524    FORMAT(2F8.2,2F10.0,F6.0,F10.0,3F9.2)
  35     CONTINUE
C
C        SUMMARIZE CRANE SUPPORTING PLATFORM MOTION
C
         WRITE(IWRT1,600) SIGHEV, SIGPCH, SIGROL, SIGWAV
  600    FORMAT(//' SINGLE AMPLITUDE CRANE PLATFORM MOTION STATISTICS',//
       $        5X, ' SIGNIFICANT HEAVE           ', F10.2, ' FT', /
       $        5X, ' SIGNIFICANT PITCH           ', F10.2, ' DEG', /
       $        5X, ' SIGNIFICANT ROLL            ', F10.2, ' DEG', //
       $        ' SIGNIFICANT WAVE HEIGHT     ', 5X, F10.2, ' FT'/)
  800    CONTINUE
C
C        PREPARE FINAL RATING CHART IN STANDARD FORMAT
C
         WRITE(IWRT1, 805)
  805    FORMAT('1SAE J1366 CRANE RATING CHART FOR A CRANE MOUNTED ON',
       $        ' A FLOATING PLATFORM'//)
         WRITE(IWRT1,810) MANFAC, CRANE(1:10), SERIAL, BL, NAMSHP, DKELV,
       $      CRX, CRY, DKBF
  810    FORMAT( 5X, 'MANUFACTURER: ', A40, /,
       $ 5X, 'CRANE MODEL: ', A10, ' SERIAL NUMBER: ', A10, ' BOOM LENGTH'
       $     , F8.2, ' FT', //5X, 'CRANE SUPPORTING PLATFORM: ', A40 /,
```

```
        $ 5X, 'DISTANCE FROM PLATFORM DECK TO SEA LEVEL',19X,F10.2, ' FT'/
        $    5X, 'CRANE LOCATION: DISTANCE FROM STERN TO CENTER OF ',
        $    'ROTATION ', 4X, F7.2, ' FT',/
        $    21X, 'DISTANCE FROM PORT SIDE TO CENTER OF ROTATION ', F7.2,
        $    ' FT',/ 21X, 'DISTANCE FROM PLATFORM DECK TO BOOM FOOT ',
        $    5X, F7.2, ' FT'//)
          WRITE(IWRT1,830) (WINSTR(J), J = 1, NUMSEA)
830   FORMAT( 10X, 'BOOM    BOOM STATIC    DYNAMIC RATINGS (LB) AT ',
        $    'THE FOLLOWING', / 9X, 'RADIUS  ANGLE  RATING  WAVE ',
        $    'INSTRUMENT READINGS, HBAR/TBAR (FT/SEC)'/,
        $    10X, '(FT)    (DEG)   (LB)', 5F8.2 /)
          WRITE(IWRT1, 835) NUMPRT
835   FORMAT( 27X, I2, '-PART MAIN HOIST LINE'/)
          DO 850 I = 1, NUMRAD
          STATIC = AMIN1(SLAND(I)/1.33, PART*BRKSTR/5.0)
          WRITE(IWRT1,840) BRAD(I), BANGD(I), STATIC, (DYNLDM(I,J),
        $    J = 1, NUMSEA)
840   FORMAT(7X, 2F8.1, 6F8.0)
850   CONTINUE
          WRITE(IWRT1, 855)
855   FORMAT(/ 27X, ' 1-PART WHIP HOIST LINE' /)
          DO 860 I = 1, NUMRAD
          STATIC = AMIN1(SLAND(I)/1.33, BRKSTR/5.0)
          WRITE(IWRT1,840) BRAD(I), BANGD(I), STATIC, (DYNLDS(I,J),
        $    J = 1, NUMSEA)
860   CONTINUE
          IF(ITYPE .EQ. 'F' .OR. ITYPE .EQ. 'f') WRITE(IWRT1,845)
845   FORMAT(/////' **** THESE RATINGS DO NOT CONSIDER MOTION ',
        $         'OF THE CRANE SUPPORTING PLATFORM')
          CLOSE(IRED1)
          CLOSE(IWRT1)
          STOP
          END
```

```
      SUBROUTINE BOAT(TBAR,H13,BETA,R,ALPHA,WAVLEN,DD,VD,AD,WCOS,NUMSIM)
C
C       COMPUTE THE MOTION OF A WORK BOAT ASSUMING PERIODIC
C       MOTION, ALSO COMPUTE THE PERIODIC MOTION FOR THE
C       CRANE PLATFORM
C
      DIMENSION DD(101),VD(101),AD(101), WCOS(101)
      TWOPI = 2.0 * 3.141597
      OMEGA = TWOPI / TBAR
      THETA = (BETA - ALPHA) * 3.14159 / 180.0
      PHI = TWOPI * R * COS(THETA) / WAVLEN
      A13 = H13 / 2.0
      DO 10 I = 1, NUMSIM
      T = FLOAT(I-1) / FLOAT(NUMSIM - 1) * TBAR
      DD(I) = A13 * SIN(OMEGA * T + PHI)
      VD(I) = OMEGA * A13 * COS(OMEGA * T + PHI)
      AD(I) = - OMEGA**2 * A13 * SIN(OMEGA * T + PHI)
      WCOS(I) = COS(OMEGA * T)
  10  CONTINUE
      RETURN
      END




      SUBROUTINE BPVEL(RX,RY,H13,TBAR,DEPTH,BETA,STNVAR,BPVVEL,NFREQ)
C
C       COMPUTE THE BOOM POINT VERTICAL VELOCITY
C
      COMMON Z(80), PHI(80), THE(80), AZ(80), APHI(80), ATHE(80),
     $      W(80), K(80)
      COMMON /OUTPUT/ SIGHEV, SIGPCH, SIGROL, SIGWAV
      DIMENSION ZR(80), ZI(80), THER(80), THEI(80), PHIR(80),
     $  PHII(80), PR(80), PI(80), VVRAO(80), PSR(80),
     $  PSI2(80), PERIOD(80), WAVEL(80),
     $  WAVPSD(80), VVPSD(80), HEVPSD(80), PCHPSD(80), ROLPSD(80)
      REAL K
      DOUBLE PRECISION EXPON
      TWOPI = 2.0 * 3.14159
      RADDEG = 180.0 / 3.14159
      G = 32.2
      BTA = BETA * 3.14159 / 180.0
      DO 35 N = 1, NFREQ
C
C       COMPUTE THE RESPECTIVE DISPLACEMENT AUTO SPECTRA WITH
C       RESPECT TO THE POINT OF INTEREST.
C
      PERIOD(N) = TWOPI / W(N)
      WAVEL(N) = TWOPI / K(N)
      ZR(N) = Z(N) * COS(AZ(N))
      ZI(N) = Z(N) * SIN(AZ(N))
      THER(N) = THE(N) * COS(ATHE(N))
      THEI(N) = THE(N) * SIN(ATHE(N))
      PHIR(N) = PHI(N) * COS(APHI(N))
      PHII(N) = PHI(N) * SIN(APHI(N))
```

```
C
C           TRANSFORM MOTION TO BOOM TIP FROM CENTER OF GRAVITY
C
      PR(N) = ZR(N) - RX * THER(N) + RY * PHIR(N)
      PI(N) = ZI(N) - RX * THEI(N) + RY * PHII(N)
C
C        COMPUTE THE VERTICAL VELOCITY AUTO SPECTRA GIVEN THE
C        DISPLACEMENT AUTO SPECTRA
C
      VVR = + W(N) * PI(N)
      VVI = - W(N) * PR(N)
      VVRAO(N) = SQRT(VVR*VVR + VVI*VVI)
C
C           FROM THE BRETSCHNEIDER WAVE AUTO SPECRA MODIFIED FOR
C           SHALLOW WATER
C
      A = 263.0 * H13**2 / TBAR**4
      B = 1052.0 / TBAR**4
      EXPON = - B / W(N) ** 4
      COEF  =   A / W(N) ** 5
      IF(EXPON .LT. 100.0 .AND. EXPON .GT. -600.0) THEN
          WAVPSD(N) = COEF * DEXP(EXPON)
          ELSE
          WAVPSD(N) = 0.0
          ENDIF
      DK = DEPTH * K(N)
      SW = 1.0
      IF(DK .LT. 20.0)
     $  SW = 2.0 * COSH(DK)**2 / (2.0 * DK + SINH(2.0 *DK))
      WAVPSD(N) = SW * WAVPSD(N)
C
C           COMPUTE THE BOOM POINT VERTICAL VELOCITY, HEAVE, PITCH, AND
C           ROLL AUTO SPECTRA FOR A DESIRED SEA STATE
C
      VVPSD(N) = VVRAO(N)**2 * WAVPSD(N)
      HEVPSD(N) = Z(N)**2 * WAVPSD(N)
      PCHPSD(N) = THE(N)**2 * WAVPSD(N)
      ROLPSD(N) = PHI(N)**2 * WAVPSD(N)
   35 CONTINUE
C
C           COMPUTE SIGNIFICANT VALUES FOR VERTICAL VELOCITY, HEAVE, PITCH,
C           AND ROLL BY SOLVING FOR THE AREA UNDER THE SPECTRA AND
C           APPLING APPROPIATE SATISTICAL FACTORS
C
      N1 = NFREQ - 1
      VARNCE = 0.0
      VARHEV = 0.0
      VARPCH = 0.0
      VARROL = 0.0
      VARWAV = 0.0
```

```
          DO 45 N = 1, N1
          VARNCE = VARNCE + (W(N+1) - W(N)) * (VVPSD(N+1) + VVPSD(N))/2.0
          VARHEV = VARHEV + (W(N+1) - W(N)) * (HEVPSD(N+1)+HEVPSD(N))/2.0
          VARPCH = VARPCH + (W(N+1) - W(N)) * (PCHPSD(N+1)+PCHPSD(N))/2.0
          VARROL = VARROL + (W(N+1) - W(N)) * (ROLPSD(N+1)+ROLPSD(N))/2.0
          VARWAV = VARWAV + (W(N+1) - W(N)) * (WAVPSD(N+1)+WAVPSD(N))/2.0
  45      CONTINUE
          SIGMA = SQRT(VARNCE)
          SIGHEV = SQRT(VARHEV) * 2.0
          SIGPCH = SQRT(VARPCH) * 2.0 * RADDEG
          SIGROL = SQRT(VARROL) * 2.0 * RADDEG
          SIGWAV = SQRT(VARWAV) * 4.0
          BPVVEL = STNVAR * SIGMA
          RETURN
          END




          SUBROUTINE FREQ(H,FRQMIN,FRQMAX,OMEGA,K,NUMFRQ,IWRT1)
          REAL K(80), OMEGA(80)
C
C              FREQ GENERATES ANGULAR FREQUENCIES AND WAVE NUMBERS THAT
C      WILL BE USED TO COMPUTE THE FREQUENCY DEPENDENT-TERMS IN THE
C      EQUATIONS OF MOTION.
C
C
C              CALCULATE THE VALUE FOR EACH OMEGA BETWEEN THE MAXIMUM
C      AND MINIMUM FREQUENCY.
C
          DELFRQ = (FRQMAX-FRQMIN)/FLOAT(NUMFRQ-1)
          DO 25 N = 1, NUMFRQ
  25      OMEGA(N) = FRQMIN + FLOAT(N-1) * DELFRQ
C
C              THE FOLLOWING LOOPS CONTAIN AN INTERATIVE SCHEME TO SOLVE
C      THE TRANSCENDENTAL FUNCTION
C                  OMEGA**2 / G = K * TANH(K * H)
C      TO DETERMINE THE WAVE NUMBER K FOR A GIVEN FREQUENCY OMEGA (G IS
C      THE GRAVENTATIONAL CONSTANT 32.2 FT / SEC**2 AND H IS THE DEPTH
C      OF WATER).  THE WAVE NUMBER K IS THE MAGNITUDE OF THE WAVE VECTOR.
C      THE X AND Y COMPONENTS OF THE WAVE VECTOR, WNXX AND WNYY, ARE ALSO
C      COMPUTED.
C
          G = 32.2
          DO 100 N=1,NUMFRQ
          U = OMEGA(N)**2/G
          XO = U
          DO 90 L = 1, 200
          T = TANH(XO*H)
          X1 = XO + ((U -XO * T) / H ) / (XO - U * T + T / H)
          IF(ABS(X1-XO).LT.1.E-6*ABS(XO))GO TO 99
          XO = X1
  90      CONTINUE
```

```
      WRITE(IWRT1,602) N
 99   K(N) = X1
100   CONTINUE
      RETURN
602   FORMAT('0*** WARNING *** K( ', I2, ' DID NOT CONVERGE BEFORE',
     $        '200 ITERATIONS ')
      END




      SUBROUTINE FRAME(NM,NJ,X,Y,XRST,YRST,ZRST,JRER,KRER,JJ,JK,AX,IZ,
     $     E,A,D)
C
C        FRAME IS A GENERALIZED FRAME ANALYSIS PROGAM AS DISCUSSED IN
C        ANALYSIS OF FRAMED STRUCTURES BY JM GERE AND W WEAVER, 1965,
C        VAN NOSTRAND REINHOLD COMPANY.  THE ALGORITHM HAS BEEN MODIFIED
C        TO ALLOW SUPPORT SETTLEMENT AND MEMBER END RELEASES.
C
      SAVE
      DOUBLE PRECISION S, AC
      REAL IZ,L,MS
      INTEGER XRST,YRST,ZRST
      COMMON /STIFF/ S(150,150), AC(150)
      DIMENSION X(50),Y(50),AX(50),IZ(50),L(50),CX(50),CY(50),
     1JJ(50),JK(50),XRST(50),YRST(50),ZRST(50),XSETT(50),YSETT(50),
     2ZSETT(50),MS(6,6),NH(6),NV(6),A(150),AML(50,6),
     3AE(150),D(150),AM1(50),AM2(50),AM3(50),AM4(50),AM5(50),
     4AM6(50),R(150),XREAC(50),YREAC(50),ZREAC(50),HED(12), E(50),
     5 JRER(50), KRER(50)
C
      DATA XSETT, YSETT, ZSETT /50*0.0, 50*0.0, 50*0.0/,
     $    AML /300*0.0/, AE /150*0.0/
C
C
      NLJ = 0
      NLM = 0
C
C        MEMBER LENGTH AND DIRECTION COSINES
C
      DO 20 I=1,NM
      JKI=JK(I)
      JJI=JJ(I)
      XCL=X(JKI)-X(JJI)
      YCL=Y(JKI)-Y(JJI)
      L(I)=SQRT(YCL**2 + XCL**2)
      CX(I)=XCL/L(I)
      CY(I)=YCL/L(I)
   20 CONTINUE
C
C        FORM MEMBER STIFFNESS AND GLOBAL STIFFNESS MATRICES
C
      NJ3=3*NJ
```

```
   35 CONTINUE
      DO 450 I=1,NJ3
      DO 450 J=1,NJ3
  450 S(I,J)=0.0
      DO 500 I=1,NM
      SCM1=(E(I)*AX(I))/L(I)
      SCM2=(4.0*E(I)*IZ(I))/L(I)
      SCM3=(1.5*SCM2)/L(I)
      SCM4=(2.0*SCM3)/L(I)
      IF(JRER(I) .EQ. 1 .OR. KRER(I) .EQ. 1) THEN
      SCM2 = 3.0 * SCM2 / 4.0
      SCM3 = SCM3 / 2.0
      SCM4 = SCM4 / 4.0
      ELSE
      END IF
      MS(1,1)=SCM1*(CX(I))**2+SCM4*(CY(I))**2
      MS(4,4)=MS(1,1)
      MS(1,4)=-MS(1,1)
      MS(4,1)=MS(1,4)
      MS(1,2)=(SCM1-SCM4)*CX(I)*CY(I)
      MS(2,1)=MS(1,2)
      MS(4,5)=MS(1,2)
      MS(5,4)=MS(1,2)
      MS(1,5)=-MS(1,2)
      MS(5,1)=-MS(1,2)
      MS(2,4)=-MS(1,2)
      MS(4,2)=-MS(1,2)
      MS(1,3)=-SCM3*CY(I)
      MS(3,1)=-SCM3*CY(I)
      MS(1,6)=-SCM3*CY(I)
      MS(6,1)=-SCM3*CY(I)
      MS(3,4)=-MS(1,3)
      MS(4,3)=-MS(1,3)
      MS(4,6)=-MS(1,3)
      MS(6,4)=-MS(1,3)
      MS(2,2)=SCM1*(CY(I))**2+SCM4*(CX(I))**2
      MS(5,5)=MS(2,2)
      MS(2,5)=-MS(2,2)
      MS(5,2)=-MS(2,2)
      MS(2,3)=SCM3*CX(I)
      MS(3,2)=SCM3*CX(I)
      MS(2,6)=SCM3*CX(I)
      MS(6,2)=SCM3*CX(I)
      MS(3,5)=-MS(2,3)
      MS(5,3)=-MS(2,3)
      MS(5,6)=-MS(2,3)
      MS(6,5)=-MS(2,3)
      MS(3,3)=SCM2
      MS(6,6)=SCM2
      MS(3,6)=SCM2/2.0
      MS(6,3)=SCM2/2.0
```

```
      IF(JRER(I) .EQ. 1) THEN
      MS(2,3) = 0.0
      MS(3,2) = 0.0
      MS(3,3) = 0.0
      MS(3,5) = 0.0
      MS(3,6) = 0.0
      MS(5,3) = 0.0
      MS(6,3) = 0.0
      ELSE
       END IF
      IF(KRER(I) .EQ. 1) THEN
      MS(2,6) = 0.0
      MS(3,6) = 0.0
      MS(5,6) = 0.0
      MS(6,2) = 0.0
      MS(6,3) = 0.0
      MS(6,5) = 0.0
      MS(6,6) = 0.0
      ELSE
      END IF
      NH(1)=3*JJ(I)-2
      NH(2)=3*JJ(I)-1
      NH(3)=3*JJ(I)
      NH(4)=3*JK(I)-2
      NH(5)=3*JK(I)-1
      NH(6)=3*JK(I)
      DO 501 KS=1,6
  501 NV(KS)=NH(KS)
      DO 502 J=1,6
      DO 503 K=1,6
      K3=NV(J)
      L3=NH(K)
  503 S(K3,L3)=S(K3,L3) + MS(J,K)
  502 CONTINUE
  500 CONTINUE
      DO 700 K=1,NJ
      J1=3*K-2
      J2=3*K-1
      J3=3*K
      IF(XRST(K) .EQ. 0) GO TO 710
      S(J1,J1)=10.**25
  710 IF(YRST(K) .EQ. 0) GO TO 715
      S(J2,J2)=10.**25
  715 IF(ZRST(K) .EQ. 0) GO TO 700
      S(J3,J3)=10. **25
  700 CONTINUE
      DO 750 I=2,NJ3
      MK=NJ3-I+1
      NC=0
      DO 752 J=1,MK
      II=I+NC
      S(I,J)=S(I,II)
  752 NC=NC+1
```

```
  750 CONTINUE
      DO 760 I=2,NJ3
      MN=NJ3-I+2
      DO 761 J=MN,NJ3
  761 S(I,J)=0.0
  760 CONTINUE
C
C     FORM THE NODAL LOAD VECTOR, BEGIN BY FORMING THE EAUIVALENT
C     JOINT LOAD VECTOR (AE) FROM THE MEMBER LOAD VECTOR (AML).
C     FORM THE COMBINED LOAD VECTOR (AC) BY ADDING THE EQUIVALENT
C     LOAD VECTOR TO THE NODAL LOAD VECTOR (A).
C
      DO 81 I=1,NM
      JA=3*JJ(I)-2
      JB=3*JJ(I)-1
      JC=3*JJ(I)
      JX=3*JK(I)-2
      JY=3*JK(I)-1
      JZ=3*JK(I)
      AE(JA)=AE(JA)-AML(I,1)*CX(I)+AML(I,2)*CY(I)
      AE(JB)=AE(JB)-AML(I,1)*CY(I)-AML(I,2)*CX(I)
      AE(JC)=AE(JC)-AML(I,3)
      AE(JX)=AE(JX)-AML(I,4)*CX(I)+AML(I,5)*CY(I)
      AE(JY)=AE(JY)-AML(I,4)*CY(I)-AML(I,5)*CX(I)
      AE(JZ)=AE(JZ)-AML(I,6)
   81 CONTINUE
      DO 82 K=1,NJ3
   82 AC(K)=A(K)+AE(K)
      DO 85 J=1,NJ
      J5=3*J-2
      J6=3*J-1
      J7=3*J
      IF(XRST(J) .EQ.0) GO TO 83
      AC(J5)=XSETT(J)*10.**25
   83 IF(YRST(J) .EQ.0) GO TO 84
      AC(J6)=YSETT(J)*10.**25
   84 IF(ZRST(J) .EQ.0) GO TO 85
      AC(J7)=ZSETT(J)*10.**25
   85 CONTINUE
C
      CALL SOLVE(NJ3,NJ3,0)
C
C     FILL THE FINAL DISPLACEMENT VECTOR WITH THE SOLUTION RESULTS.
C
      DO 90 KA=1,NJ3
      D(KA) = AC(KA)
      IF( 3S(D(KA)) .LT. 1.0E-15) D(KA)=0.0
   90 CON.INUE
      RETURN
      END
```

```
      SUBROUTINE SOLVE (II,JB,LETHAL)
C
C     SOLVE A SET OF LINEAR EQUATIONS USING THE CHOLESKY METHOD.
C     A IS THE SYMMETRIC UPPER TRIANGULAR STIFFNESS MATRIX, F IS
C     THE LOAD VECTOR AND THE SOULTION DISPLACEMENT VECTOR.
C
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON /STIFF/ A(150,150), F(150)
      DO 20 IC = 1,II
      IF (A(IC,1) .GT. 1.0E-6) GO TO 20
      LETHAL = 1
      GO TO 4000
   20 CONTINUE
      A(1,1) = DSQRT(A(1,1))
      DO 100 J=2,JB
  100 A(1,J) = A(1,J)/A(1,1)
      JMONE = JB -1
      DO 105 I=2,II
      IPBW = I + JMONE
      DO 105 J=I,IPBW
      SUM = 0.0
      IC = I
      JC = J - I +1
      IF( J .NE. I) GO TO 103
      DO 101 L= 1,JMONE
      LP = I - L
      LJC = J - LP + 1
      NCK1 = L - LP
      IF (NCK1 .GT. JMONE) GO TO 102
      IF (LP .LT. 1) GO TO 102
  101 SUM = SUM + A(LP,LJC) **2
  102 Q1 = A(IC,JC) - SUM
      A(IC,1) = DSQRT(Q1)
      GO TO 105
  103 SS= 0.0
      DO 104 L=1,JB
      LP=I-L
      LJC = J-LP+1
      LIC = I-LP+1
      NCK2= I-LP
      NCK3 = J-LP
      IF (NCK2 .GT. JMONE) GO TO 1050
      IF (NCK3 .GT. JMONE) GO TO 1050
      IF (LP .LT. 1) GO TO 1050
  104 SS = SS + A(LP,LIC)*A(LP,LJC)
 1050 A(IC,JC) = (A(IC,JC) - SS)/A(I,1)
  105 CONTINUE
      F(1) = F(1) / A(1,1)
      DO 1060 I=2,II
      SK=0.0
```

```
      DO 106 MT=1, JMONE
      M = I-MT
      IC = I-M+1
      NCK4= I-M
      IF (NCK4 .GT. JMONE) GO TO 1060
      IF (M .LT. 1) GO TO 1060
  106 SK = SK + A(M,IC)*F(M)
 1060 F(I) = (F(I)-SK)/A(I,1)
      F(II) = F(II)/A(II,1)
      IMONE = II-1
      DO 109 I = 1,IMONE
      SX = 0.0
      K = II-I
      LS = K+1
      DO 108 L=LS,II
      LC = L-K+1
      NCK5 = L-K
      IF (NCK5 .GT. JMONE) GO TO 109
  108 SX = SX+A(K,LC)*F(L)
  109 F(K) = (F(K) - SX)/A(K,1)
 4000 RETURN
      END
```

SECTION III
RELATED DOCUMENTATION

The Naval Civil Engineering Laboratory has three internal documents that are relevant to the crane issue. They are included here as appendixes to further disseminate the information.

In 1976, Frank R. Johnson, prepared "Procedures for determining load ratings for truck cranes supported on a floating platform moored in the open ocean." Dynamic load ratings that relate load radius to maximum allowable load were calculated. The expected operating life and maintenance and inspection requirements were established with respect to prolonged service periods. See Appendix D for this material.

Also in 1976, Carley C. Ward prepared "Dynamic vertical forces on a crane loading (unloading) a floating platform." The objective of this study was to find the dynamic forces on a marine crane caused by lifting a load from, or setting a load on, a moving deck. First the response caused by the application of the load weight was determined. The effects of deck and hoist relative velocity were also included. Then using vector addition the combined dynamic force was computed. Finally, the results were related to wave characteristics so that derating charts could be developed. See Appendix E for this material.

In 1978, Carley C. Ward and Frank R. Johnson prepared "Dynamic loads on a shipboard crane boom due to ship motion." nonlinear equations for determining dynamic loads on a shipboard crane boom due to ship motion were developed using vector analysis and rotating coordinate frames. Once computed, the load functions were incorporated into the flexible boom matrix equation of motion. The elastic response of the boom to these time varying inertial loads could now be computed. See Appendix F for this material.

Appendix D

PROCEDURES FOR DETERMINING LOAD RATINGS FOR
TRUCK CRANES SUPPORTED ON A FLOATING PLATFORM
MOORED IN THE OPEN SEA

by

Frank R. Johnson, Jr.

February 1976

LOAD RATINGS FOR TRUCK CRANES SUPPORTED ON A
FLOATING PLATFORM MOORED IN THE OPEN SEA

INTRODUCTION

The amphibious operations of the United States Armed Forces require
containerized cargo to be unloaded from container ships in areas where
developed container handling ports are not available. Plans are being
developed requiring container ship unloading in the open sea. These
plans consider using mobile cranes on floating platforms (i.e., barges
or ships) in the open sea. Manufacturers of mobile cranes provide maximum
load ratings to promote safe crane operation. However, the published max-
imum load ratings '' . . . make no allowances for such factors as the
effect of freely suspended loads, wind, ground conditions, inflation
of rubber tires, and operating speeds.''[1]

Objective

The study will evaluate the performance of mobile cranes when they
are supported on floating platforms moored in the open sea. Dynamic
load ratings that relate load radius to maximum allowable load will be
calculated. The expected operating life and maintenance and inspection
requirements will be established with respect to prolonged service
periods.

Scope

The scope of the work will be based upon two concept scenarios and
the crane service conditions associated with these concepts. The temporary
crane discharge facility (TCDF), the first scenario, requires the crane
to operate from a floating barge or a small ship. The containership is
along one side of the crane supporting platform and the lighterage is
along the other side. Therefore, the crane operating sector is a 180°
arc.

The crane on deck concept (COD) requires the crane to move down the
deck of the container ship as it unloads the cargo so the ship can be
unloaded symmetrically in order to maintain trim. Deck reinforcement and
bridging between hatches will be required to support the crane. With the
lighterage alongside the container ship, the crane operating sector
will therefore also be a 180° arc.

---

[1] Harnischfeger, P&H Construction Equipment sales literature for
the P&H 6250-TC crane.

The containership must be able to start its return voyage a few days from its arrival at the operational area. Table 1 presents the environmental and physical conditions associated with the unloading operation. The offloading scenario, developed to meet the mandatory rapid turnaround requirement is presented in Table 2.

There are a significant number of parameters associated with the crane analysis. Structural parameters include geometric dimensions, cross section properties, and material properties. Environment parameters include wind conditions, wave direction, and sea states. Physical parameters relate to the platform description and platform types. With regard to endurance, the crane operating sectors, load radii, duty cycle, average crane cycle, average hook load duration and the gross weight mix are also important parameters. These parameters are addressed in Tables 1 and 2. One of the initial project objectives will be establishing the parameters that govern the performance of the crane so the number of cases studied may be reduced.

The most difficult parameters are associated with the motion simulation. The motions requiring simulation include platform motion, restrained pendulum motion, booming motion, rotating motion, and lifting motion. These motions are all interrelated which further complicates the simulation. However, one of the initial efforts will be directed toward the development of equations of motion that will simulate the complex motion experienced in an offloading operation. The work summarized within this Technical Memorandum covers that from start of the project through Dec 31, 1976.

Approach

The expense of a failure in a tactical situation far exceeds the value of the crane. Therefore, the steps to be taken to accomplish the objectives of this project will have checks and balances to insure that proper conclusions are drawn. Alternate solution methods will be employed to validate the data produced in this study.

Results from destructive static tests and failure criteria obtained from literature and crane manufacturers will be used to gain insight to potential failure areas. The structural model should be refined so it will capture the proper failure modes. The model will be developed based on known failure modes obtained through static destructive testing.[1,2] Evaluation of the results obtained from loading the analytical model should be based upon established criteria. The Column Research Council is actively engaged in establishing failure criteria for beam-columns. Furthermore, the American Institute of Steel Construction is also engaged in column failure criteria development. However, some crane manufacturers have established proprietary design criteria. Therefore, the results of the dynamic structural analysis should be evaluated with failure criteria similar to that used by each manufacturer. The failure modes discovered in this study will be primarily induced by ship motion since the static loads are much less critical.

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[1] Society of Automotive Engineers, ''Crane Structures - Method of Tests - SAE J987,'' New York, NY, Jun 1968.

[2] Society of Automotive Engineers, ''Destructive Testing of Crane Booms,'' by C. A. Brolin, et al., New York, NY, Sep 1972.

The ship motion simulation will be adapted to the needs of the structural analysis and aimed at identification of the failure modes. The required simulated information is limited to the deflections and rotations at the center of gravity of the platform. Accelerations at the center of gravity of the ship are also required. Studies involving the displacement and acceleration at the center of gravity of the ship will be conducted to establish conditions appropriate for the structural analysis. Appropriate transformations will also be derived to transform the reference point from the center of gravity of the platform to appropriate points on the boom.

The equations of motion will be written using two approaches. Newtonian mechanics will be used to derive the equations of motion from the force point of view. A second approach for verification will employ Lagrange's equations which use energy principles to derive the equations of motion. As mentioned in the previous section contributions due to platform motion, restrained pendulum motion, booming motion, rotation motion, and lifting motion will be considered.

The equations of motion will be solved at discrete points throughout the structure. The three-dimensional boom and pendant structure will be modeled and appropriate static and dynamic loads will be included, such as the loads induced by wind, tag lines restraining pendulum motion, and the lifted weight. Investigations will be made with regard to linear and nonlinear analytic models. The results of the analysis will include stress and deflection in the structural members. These results will be evaluated based on the established failure criteria.

Many of the crane manufacturers utilize static analysis techniques to analyze the crane structures. A simplified dynamic model will be used to develop equivalent static loads so the manufacturers can conduct an equivalent static analysis as a means of correlating the results obtained from the full dynamic approach.

The initial results of the analysis will be used to set up instrumentation for a non-destructive test of a crane in the operating environment. The cranes utilized in this test will be instrumented so the analytical results may be compared with actual conditions.

The expected life of the crane under prolonged service conditions and the maintenance and inspection requirements will be established after satisfactory results have been obtained from the structural analysis.

Background

The Civil Engineering Laboratory began the investigations outlined above during 1973. The initial analysis contract was awarded to Harnischfeger Corporation, the manufacturer of P&H construction machines. Harnischfeger in turn consulted with Dr. William Saul of the University of Wisconsin at Madison. Dr. Saul had a three-dimensional frame analysis program used to analyze buildings subjected to dynamic wind and earthquake loads. However, to solve the problem of the crane mounted on a floating platform, Dr. Saul required information regarding the motion of the supporting platform.

The Civil Engineering Laboratory developed a computer program to calculate the relative motion of one vessel with respect to another. This program, RELMO, was developed from state-of-the-art procedures and modified for use in shallow waters. The Laboratory provided this program to the University of Wisconsin, Madison, and Dr. Saul incorporated the relative motion simulation into the structural analysis program. Later, under separate contract, the original program was enhanced and made available to this Laboratory.

The remainder of this report will summarize the results of the contracts with P&H and the University of Wisconsin. The summary will be directed toward (1) the RELMO program interface with Wisconsin program, (2) the Wisconsin program, and (3) the P&H crane boom analysis results.

SHIP MOTION SIMULATION

The motion of the supporting platform is calculated using strip theory: Grim's method, shallow water coefficients, and the Pierson-Moskawitz fully developed spectrum.[1] The objective is to calculate the displacement and rotation of the platform at the center of gravity. The velocity and acceleration of the platform motion can be obtained by differentating with respect to time. The theory employed in the ship motion simulation follows.

The equations of motion derived from Newtonian mechanics form the basic of the ship motion calculations. The force components due to: (1) the inertia force of the body and fluid, (2) the damping force, (3) the hydrostatic restoring force, and (4) the mooring force are summed and equated to the wave exciting force. The force components include the translational and rotational components or six degrees of freedom at the platform center of gravity.

The assumptions employed in the formulation of the six equations of motion are discussed elsewhere.[2] However, a few of these assumptions impact the approach taken in the structural analysis phase of the crane boom study. These assumptions are: (1) ship is considered a rigid body, (2) linear equations of motion are used through limiting the motions to small displacements and rotations, (3) the motion in an irregular or random sea is based on the Pierson-Moskowitz spectrum for fully developed wind-driven seas, (4) the added or hydrodynamic mass coefficients used in the calculation of force components are independent of water depth, that is the same value is used for deep and shallow water, (5) the deep water potential used to calculate the wave exciting force is modified for shallow water, and (6) a shallow water coefficient derived by Burnside was used to modify the Pierson-Moskowitz spectrum. With these primary assumptions the equations of motion are developed and solved.

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[1] Civil Engineering Laboratory Technical Note N-1371, ''The Motion of Floating Advanced Base Component In Shore Water - A Comparison Between Theory and Field Test Data,'' by D. A. Davis and H. S. Zwibel, Port Hueneme, CA, Jan 1975.

[2] Hydronamics, Incorporated, Technical Report 636-1, ''Rough Water Mating of Roll-on/Roll-off Ships With Beach Discharge Lighters,'' by T. Hsieh, C. C. Heu, D. P. Roseman, and W. C. Webster, Laurell, MD, Jul 1967.

The six equations of motion have a complex harmonic solution. The real and imaginary components of the solution represent the amplitude and phase of the platform motion. These values are represented at the center of gravity of the platform and are dependent on frequency and phase of the incident wave. The amplitudes of the platform motion are for a unit incident wave, because the wave exciting force was calculated from the potential energy of a unit wave. Therefore, the motion amplitudes are commonly called response amplitude operators.

A stationary Gaussian random process is used to transform the response amplitude operators which are harmonic into a stochastic representation of a wind-generated sea state. The Pierson-Moskowitz fully developed spectrum for wind generated waves and modified for shallow water is used to simulate the irregular wave motion in the time domain as the summation of cosine waves each with a different frequency and with a random phase angle uniformly distributed between $[0, 2\pi]$. The elements of the ship motion vector are given by

$$X_{ci}(t) = \sum_{n=1}^{N} [2\Delta\omega \, S_i(\omega_n)]^{1/2} \cos(\varepsilon_n + \phi_{ni} - \omega_n t)$$

where

$X_{ci}(t)$ is one of the six (represented by i) components of the platform motion at the center of gravity;

$\Delta\omega$ is the interval chosen in the frequency domain;

$$S_i(\omega_n) = [RAO(\omega_n)]^2 \, S_s(\omega_n)$$

where

$RAO(\omega_n)$ is the complex harmonic response amplitude operator,

$S_s(\omega_n)$ is the modified Pierson-Moskowitz spectrum given by

$$S_s(\omega_n) = \left[\frac{\mathrm{Cosh}^2\left(\dfrac{2\pi h}{L_s}\right)}{\dfrac{4\pi h}{L_s} + \mathrm{Sinh}\left(\dfrac{4\pi h}{L_s}\right)} \right] \frac{0.0081g^2}{\omega_n^5} e^{\dfrac{-33.56}{\omega_n^4 H_{1/3}^2}}$$

where the quantity in the bracket is the shallow water coefficient and

h   is the depth of water,

L_s is the shallow water wave length,

g   is the acceleration due to gravity,

$H_{1/3}$ is the significant wave height representing the mean of 1/3 of the highest waves in a wave height population.

The idealized model shown in the figure has three reference systems. The inertial reference system is denoted as X_i, Y_i and Z_i where O_i is the origin. The floating platform and structure reference systems are similarly denoted. However, the subscripts p and s are respectively employed for identification purposes. The origin of the floating platform reference system, O_p, is taken at the center of gravity of the platform. The structure system origin, O_s, is located at the base of the truck crane boom. The center of rotation of the crane upper works and the location of the boom base are not necessarily at the same point.

The floating platform, crane truck carriage, and revolving super-structures are assumed to be rigid. This assumption requires the crane supporting outriggers to be fully extended, the crane truck carriage to be lashed securely to the platform deck, and it assumes mechanical tolerences in the swing and other mechanisms are insignificant.

The boom has been modeled as two beam elements. A beam element considers in plane and out of plane bending moments, shear forces, torsion moments, and axial force. Essentially, the actual structure is modeled as a beam-column with truss supports. The nonprismatic three-dimensional lattice structure is treated as a prismatic beam-column. Calculation of the equivalent section properties will be discussed later in this report.

The boom-supporting rope structure and the load-handling rope structure have also been simplified. The running boom hoist rope, floating harness and pendents have been modeled as two truss elements. The main hoist line has also been considered as a truss element. Truss elements consider only axial forces. Since bending does not occur in a rope structure, the truss elements are reasonable. However, since the rope structure can only support tensile force, they will collapse under a compressive load. The truss elements are considered to have a preload due to the static condition so if compressive forces are formed in the dynamic condition the net result is a reduced tensile force in the rope. If this assumption were not made the problem could not be linearly solved due to the sudden change in stiffness of a slack rope.

The mass of the structure has been lumped or concentrated at six points. The concentration points are located at the boom base, pendant supports, midsection (denoted as m_3 in Figure 2) and tip of the equivalent beam-column model (denoted as m_2 in Figure 2). The masses of the hoist rope, load, hook, block, sling, and rigging are concentrated at the hook end of the main hoist rope (denoted as m_1 in Figure 2). The lumped mass at the boom midsection, boom tip and lift hook is considered in the analysis. However, the lumped mass at the boom base and at the two pendant supports is not considered since these points are not free.

Nine degrees of freedom have been chosen for this model. Node number 1, located at the lift hook, has three degrees of freedom: (1) horizontal in the plane of the boom, (2) horizontal and normal to the plane of the boom, and (3) vertical in the plane of the boom. Node number 2, located at the boom tip also has three degrees of freedom with the same orientation, and node number 3 has similar freedom. Figure 2 shows the identification numbers associated with each degree of freedom. It is pointed

out and emphasized that node number 1 is completely free to pendulate. In practice, however, the operator and/or taglines would limit the pendulum motion.

External conditions that affect the structural response of the boom and pendant structure include: specified displacements and rotation due to wave motion and occurring at the center of gravity of the floating platform; gravity loadings due to the dead weight of the boom and pendant structure; the dead weight of the hook, block, sling and rigging, and the gross weight of the container; wind loading due to the wind velocity associated with the sea conditions; and the pendulum restraint load imposed by tagline devices. Internal resisting conditions include elastic forces, inertial forces, and damping forces. The damping forces are intended to account for air resistance, friction movement, and other energy losses.

In the Wisconsin program the gravity loads, wind loading, and pendulum resistance load are not included in the dynamic analysis. Therefore, the dynamic analysis results should be combined with appropriate static analysis results in order to determine the total structural behavior. The equivalent static analysis should use a model consistent with the model used to obtain the total structural behavior.

A static load that neglects the weight of the boom pendant structure, wind pressure, and tagline loads is used as the reference condition for calculating the dynamic load factors. That is, the weight of the container load is applied at degree of freedom number 2 and a percentage of that load is applied at degrees of freedom 1 and 3, in order to account for side load due to the pendulum. The percentage is chosen based on the designer's assessment of the maximum side load condition considering an experienced operator and/or taglines that are used to limit pendulum motion. For example, Professor Saul has used 5% of the lifted load in degree of freedom number 1 and 2.5% in degree of freedom number 3. The designer who uses the dynamic load factors should use extreme care in selecting an equivalent static model so that, after the dynamic load factors have been applied, his loading condition is consistent with the dynamic loads imposed on the structure.

Equivalent Beam-Column

The calculations to reduce the three-dimensional non-prismatic lattice structure to the equivalent two-dimensional prismatic beam-column model discussed above are described below. The objective is to calculate quantities for the cross section properties (area, moment of inertia, and torsion constant) for an equivalent beam that will possess deflection properties compatible with the actual structure. The modulus of elasticity and shear modulus are assumed equal in the actual and equivalent structures.

The equivalent beam-column consists of two beam elements. One beam element extends from the boom foot to the boom midsection while the other starts at the midsection and extends to the boom tip. Depending upon the insert arrangement the beam elements are made up of full and partial boom inserts. The dimensions of the inserts, including the intersections of chords and lacings, as well as the junctions between boom sections are required. In addition, the section properties of the chords and lacings are required.

Two beam-column problems will be solved; one for the top half equivalent structure and one for the bottom half. Since the process is the same for both, only one will be discussed. The entire boom from the midsection to the tip, for example, should be modeled for a static three-dimensional frame analysis procedure. Twelve unit loading conditions will be applied to the structure to produce the deflection shapes that are used to calculate stiffness properties.[1] With the deflections known, the equivalent section properties may be calculated directly from the appropriate stiffness terms since the material and length of the actual beam and the equivalent beam are the same. The equivalent section properties can then be used with the Wisconsin program.

The effective area of the wire rope is obtained from an effective stiffness approach. The values of EA and a nominal E are obtained from the wire rope manufacturer and the effective area is calculated by

$$A_{eff} = \frac{EA}{E_{nominal}}$$

The quantities required for this calculation can be obtained from the manufacturers or from a cable handbook.

Modal Analysis

Attention will now be directed to the procedure used to obtain the desired dynamic load factors and equivalent static loads. The procedure is only outlined here and any recent text dealing with structural dynamics may be used to supplement this discussion.[2]

Equilibrium requires that the summation of the inertia and other resistive forces equals the applied forces on a structure. Thus

$$\lceil M \rfloor \{\ddot{X}_T\} + [C] \{\dot{X}_T\} + [K] \{X\} = \{P(t)\} \qquad (1)$$

where $\lceil M \rfloor$ is the lumped mass matrix of the system,

[C] is the damping matrix, which in this case represents contributions from all forms of damping,

[K] is the structure stiffness matrix,

{X} is the elastic displacements vector, i.e., relative to X_s, Y_s, Z_s

$\{\dot{X}_T\}$ is the total velocity vector, i.e., relative to X_i, Y_i, Z_i

$\{\ddot{X}_T\}$ is the total acceleration vector, and

{P(t)} is the vector of applied loads which include wind pressure gravity hook, gravity structure, and tagline loads.

[1] Gere, James M., and Weaver, Williams, Jr, ''Analysis of Framed Structures,'' Van Nostrand, Princeton, NJ, 1965, p 196-197.

[2] Hurty, W. C. and Rubinstein, M. F., ''Dynamics of Structures,'' Prentice Hall, Englewood Cliffs, NJ, 1965.

Also it is noted that in structural coordinates

$$\{X_T\} = \{X_R\} + \{X\} \tag{2}$$

where $\{X_T\}$ is the total displacement,

$\{X_R\}$ is the rigid body displacement, and

$\{X\}$ is the elastic displacement.

Equation (1) can now be written as

$$\lceil M \rfloor \{\ddot{X}_T\} + [C] \{\dot{X}_T\} + [K] \{X_T\} = [K] \{X_R\} + \{P(t)\} \tag{3}$$

However, $\{P(t)\}$ which includes the applied loads has been omitted from the analysis. This has been purposely done so the calculation results reflect only the dynamic effects due to the base motion.

The rigid body displacements $\{X_R\}$ are with respect to the structural coordinate system. However, the displacements at the centroid of the platform as calculated in the ship motion simulation are with respect to inertial coordinates. A linear transformation [T] is required to transform the displacement coordinator from the inertials coordinate system to the structure coordinate system, as follows

$$\{X_R\} = [T] \{X_c\}$$

where $\{X_R\}$ represents the rigid body displacement in structural coordinates, and

$\{X_c\}$ represents the rigid body displacements of the centroid of the ship in inertial coordinates

Equation (3) can now be expressed as

$$\lceil M \rfloor \{\ddot{X}_T\} + [C] [\dot{X}_T] + [K] \{X_T\} = [K] [T] \{X_c\} \tag{4}$$

The solution to the differential equation might be obtained by direct integration, but modal analysis or modal superposition is used instead.

Modal analysis requires two steps: (1) determining the natural frequencies and associated mode shapes for the free vibration system and (2) using the mode shapes to uncouple Equation (4) (i.e., form an independent single-degree-of-freedom equation for each degree of freedom). The power method is the numerical procedure employed to extract the eigenvalues and eigenvectors. Equation (4) can be uncoupled by appropriate substitutions that diagonalize the damping and stiffness matrices. The resulting equation is

$$\{\ddot{Z}\} + \lceil 2\xi\omega \rfloor \{\dot{Z}\} + \lceil \omega^2 \rfloor \{Z\} = [a]^T [K] [T] \{X_c\} \tag{5}$$

where ξ is the coefficient of critical damping

ω represents the natural frequencies for the mode shapes being considered,

$[a]^T$ is the transpose of the matrix of eigenvectors,

$[K]$ is the structural stiffness matrix,

$[T]$ is the coordinate transformation matrix,

$\{X_C\}$ is the platform displacement vector, and

$\{Z\}$ are the modal participation factors such that

$$\{X_T\} = [a]\{Z\} \tag{6}$$

where $[a]$ is the matrix of eigenvectors; that is, each column of $[a]$ is a mode shape. Equation (5) is solved by direct integration and Equation (6) is evaluated for each time step. Thus, in essence we have a matrix $[X_T]$ that has 9 rows, one for each degree of freedom, and N columns, one for each time step, and it represents the dynamic total displacement history for the time domain at each degree of freedom. The total displacement for each time step can be transformed to dynamic elastic displacements by

$$\{X\} = \{X_T\} - [T]\{X_C\}$$

since

$$\{X_T\} = \{X_R\} + \{X\} \text{ and}$$

$$\{X_R\} = [T]\{X_C\}$$

where the symbols employed have been previously defined. Of course, it is implied that this transformation is performed for each time step in order to obtain the dynamic elastic displacement history.

The elastic dynamic displacement history is searched to find the maximum and minimum displacement vector. These vectors are identified by computing the norm of each displacement vector at each time step and selecting the maximum and minimum value. Furthermore, the mean and standard deviation of the dynamic elastic displacements are also estimated for the population, assuming Gaussian distribution. However, these quantities are not immediately applicable for determining dynamic load ratings.

Dynamic load ratings require evaluation of the structural behavior relative to some established stress or deflection criteria. Crane designers are comfortable with static design techniques. Two types of information are presented to the designer so he can determine the dynamic load ratings.

First, a statistical dynamic load factor is calculated for each degree of freedom. The dynamic load factor (DLF) is defined at each degree of freedom as

$$DLF = \frac{\text{dynamic elastic displacement}}{\text{static elastic displacement}}$$

where the ratio is evaluated for the maximum and minimum displacement vector and for the dynamic elastic displacement statistics vectors. The static elastic displacement used in the denominator is obtained from the solution of

$${X_s} = [K]^{-1} {P_s}$$

where   [K]   is the structure stiffness matrix

     ${P_s}$ is the static load vector obtained from the static reference condition described on page 8

     ${X_s}$ represents the static elastic displacements at each degree of freedom.

From the dynamic load factor statistics, a most probable load factor can be selected for each degree of freedom and used in subsequent static analysis.

The second type of information available for static analysis is a set of probable equivalent static loads for each degree of freedom causing the dynamic response. These equivalent static loads can be applied to the boom structure instead of the dynamic load factors to obtain the dynamic load ratings. The equivalent static loads for each time step are calculated by

$${P_d} = [K] {X}$$

where ${P_d}$ represents the equivalent static load at each degree of freedom due to dynamic base motion for a single time step

     [K]   is the structural stiffness matrix and

     {X}   represents the dynamic elastic displacements at each degree of freedom for each time step.

As before, the maximum, minimum, estimated mean and estimated standard deviation values are determined at each degree of freedom from the results for each time step.

Dynamic Load Rating

The Wisconsin program calculations can be used in conjunction with a static crane boom analysis program to determine the loads that can be safely handled at sea. Table 3 shows typical output from the program. The program permits variable boom angles (THETA), main lifting rope lengths (VRPL), significant wave heights ($H_{1/3}$), incident wave direction (LHEAD), suspended weight, and structure rotation angles. The response statistics matrix (STM) of dynamic deflections, the dynamic load factors (DLF), and the dynamic loads matrix (PD) for each degree of freedom are printed. The estimated mean, estimated standard deviation, and the mean plus and minus one standard deviation are calculated at each of nine degrees of freedom for the population of results obtained from each time step. The maximum and minimum vectors are selected by the respective values of the norm for each vector calculated at each time step are also displayed in the table. These tables can be used to develop loading conditions for a static analysis of the crane booms conducted by the crane manufacturer. There are two ways the tables might be used.

The first way employs the dynamic load factors. Although dynamic load factors are commonly used in a single degree system, their usefulness in a multidegree system is questionable. However, assuming one desires to use this approach, the recommended procedure is outlined below:

(1) Use the dynamic load factors for degrees of freedom 1, 2, and 3 only, thus being consistent with the static reference model used in the definition of the dynamic load factor,

(2) Add one to the dynamic load factor such that

$$P_{e_i} = P_{s_i} (1 + DLF_i)$$

where P_{e_i} is the equivalent static load for degrees of freedom i where $1 \le i \le 3$

P_{s_i} is the static load for degrees of freedom i used in the static reference condition, and as well as the ensuing static analysis.

DLF_i is the probable dynamic load factor for degree of freedom i.

Note that this method does not include the boom pendant structure weight wind load, and tagline forces because the static reference condition did not include these loads. Appropriate modifications can be made to include these missing loads.

The second and possibly the preferred method of using the results utilizes the equivalent static load P_d statistics shown in Table 3 instead of the dynamic load factors. As before, the value selected from the table only includes the dynamic load due to the base motion. Therefore the load used in the final static analysis should be

$$P_{e_i} = P_{s_i} + P_{d_i}$$

where P_{e_i} is the total equivalent static load, for degree of freedom i where $1 \le i \le 9$ to be used in the ensuing static analysis,

P_{s_i} is the static load applied to the structure, for degree of freedom i assuming no base motion

P_{d_i} is the probable equivalent static load for degree of freedom i based upon the motion induced at the base of the structure by the sea conditions.

Note that this method does not require the reference static condition so it is more directly applicable.

Proper use of the statistics calculated is imperative to obtain meaningful results. The following applies to both methods explained above. The printed results include for each degree of freedom the esti-mated standard deviation and the value associated with the critical dynamic deflected shape as determined by the maximum norm. A normal distribution at each degree of freedom is assumed. A reasonable or probable design value must be selected for each degree of freedom. The value selected must be proportional to the values presented for the critical

deflected shape in order to maintain the desired shape after the design
values have been selected. The procedure for selecting reasonable design
values at each degree of freedom is outlined:

(1) Choose a probability of not exceeding the design value or of
exceeding the design value,

(2) Enter a table of the normal probability function and select the
normalized value of standard deviation associated with the desired
probability,[1]

(3) Calculate the design value by

$$X = \mu \sigma_x + m$$

where   X   represents the probable or design value,

            μ is the value selected from the normal probability function,

            σ_x is the estimated standard deviation of the population,

            m   is the estimated mean of the population.

When all of the design values have been selected at each degree of freedom,
the values are compared to the values of the critical deflected shape.
If there is a lack of correspondence, the process should be repeated.
It may be necessary to vary the design probability for each degree of
freedom to effect correspondence with the critical shape.

EQUIVALENT STATIC ANALYSIS

The Harnischfeger Corporation conducted a structural analysis of a
standard production model P&H 6250TC equipped with a container tip and
supported by a 1179 class LST. The 6250TC that was analyzed is further
described in Table 4. The load rating curve which relates the hook load
to the boom angle and load radius for fixed base conditions is illustrated
in Figure 3.

The structural analysis was performed by Harnischfeger using their
program FO7404. The University of Wisconsin Crane Analysis Program was
used to calculate the dynamic load factors that were applied to the
static loads. The boom cross sections experiencing failure conditions
and the conditions causing the failure are shown in Table 5. The
results of the stress analysis are summarized in Table 6, which pre-
sents the maximum ratios of the actual stress divided by the allow-
able stress expressed in percent. The deflection of the tip normal
to the plane of the boom is also presented.

It has been found from the results of the analysis that the P&H
6250 can be used in sea state 2 conditions where the incident waves are

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[1] CRC Standard Mathematical Tables, Twenty-Second Edition, Edited
    by S. M. Selby, CRC Press Inc, Cleveland, Ohio, 1974, p 583-591.

bow or quartering seas. The crane may also be used in sea state 3 conditions where the waves are bow seas. The boom will fail, as shown in Table 6, in sea state 2 beam seas and sea state 3 quartering and beam seas. One should also note that the maximum load used in this analysis was 20 long tons, thus this analysis supports handling of the 8 x 8 x 20 containers. However, it may be inadvisable to service fully loaded 20 LT containers because the weight of the hook, block, slings, and rigging is not considered in the analysis live load. The 8 x 8 x 40 containers should not be serviced.

There is reason to question the results of this analysis. First the maximum values of the dynamic load factors were used. With a normal distribution, the possibility of an event not exceeding one standard deviation is 84.13% while with two standard deviations the possibility is 97.72%. The maximum dynamic load factor values are usually near two standard deviations. It is believed the analyst should have assumed a more reasonable probability and calculated the appropriate dynamic load factors.

Second, the effects of the dynamic load factor normal to the boom are quite severe but the contribution of the pendulum has not been resolved. Since the model allows free pendulation, the out-of-plane dynamic load factors may be too large. Furthermore, the side load factor (2.50%) was applied to all of the out-of-plane degree of freedom dynamic load factors which may lead to improper results. Moreover, applications of out-of-plane degree of freedom dynamic load factors is at least controversial.

Third, the Harnischfeger report states the boom was failing due to side load caused by lifting load pendulation. This conclusion does not completely agree with the results they provided, because the boom also failed due to the vertical load as shown in the last six entries of Table 6. However, the hook load has exceeded the 136,500 pound rating set for a static or ground supported operations at 75° boom angle (refer to Figure 3). One can easily see that the 10 LT load (22,400 pounds) has been increased through the platform motion to an unacceptable 235,900 pounds. This increase appears unreasonable.

Fourth, the dynamic analysis did not include the wind loading on the structure. The theory employed for the ship motion simulation is based on wind driven waves. Therefore, there is a relationship between the sea state and wind velocity. The pressure on the structure resulting from the wind velocity should be included in the calculations.

CONCLUSIONS

The following can be concluded from the project work completed prior to December 31, 1975:

a. The ship motion simulation did not include the shallow water modification for the deep water spectrum.

b. The ship motion random number generator considered the open interval [0, 1] instead of the desired closed interval [0, 1]

c. Wind, gravity, and tagline loading have been omitted in the calculation of the dynamic load factor and equivalent static loads.

d. The structural model does not include continuous simulation of rotating, booming, and lowering motions.

e. Pendulum motion has not been restrained

f. The dynamic results must be superimposed with static results to get the complete structural behavior

g. The dynamic load factors are not definitive in their application to a static analysis

h. The equivalent static load may be a more realistic approach to the equivalent static analysis, than the dynamic load factor approach

i. The effort required to determine equivalent beam-column structural properties is greater than that required to set up the problem for a full three-dimensional analysis.

j. The P&H static analysis results are inconclusive as to their meaning.

RECOMMENDATIONS

Based upon the preceding conclusions, the following recommendations are made:

a. Conduct ship motion studies to determine the maximum or most probable base motions conditions.

b. Identify modes of crane boom failure from reports of controlled destructive testing.

c. Develop the equations of motion that consider rotation, booming, lifting, and restrained pendulum motions in addition to the base motion.

d. Conduct a full three-dimensional dynamic analysis.

e. Conduct another equivalent static load analysis for correlation purposes.

f. Conduct a non-destructive structural test for correlation purposes.

g. Determine the expected life of the crane critical components after the dynamic analysis has been completed.

h. Finally, develop the maintenance and inspection requirements for the crane.

ACKNOWLEDGMENTS

Container Tip
Over Rear
150 Foot Boom

Rot.

71.4 tons
71.4 tons
56.3 tons
45 tons
37 tons
31.3 tons
26.8 tons

35' R.
50' R.
60' R.
70' R.
80' R.
90' R.
100' R.

90' beam

All Lifting Capacities
Are Stated In Long Tons

Figure 1. A typical truck crane in operation position.
(After Harnischfeger P&H 6250-TC Maritime Crane
Specification sales literature.)
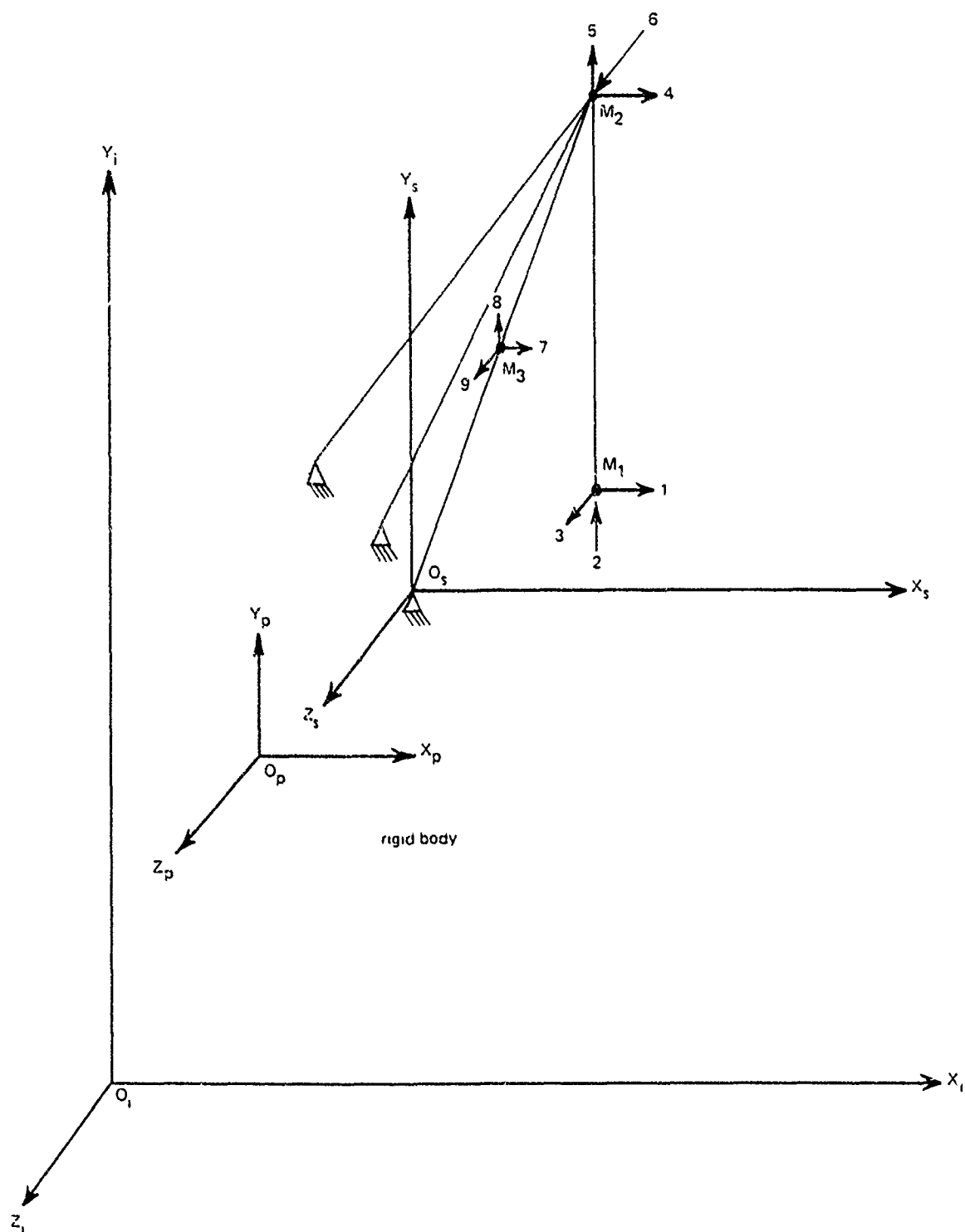
Figure 2. An idealized model of the truck crane supported on a floating platform.
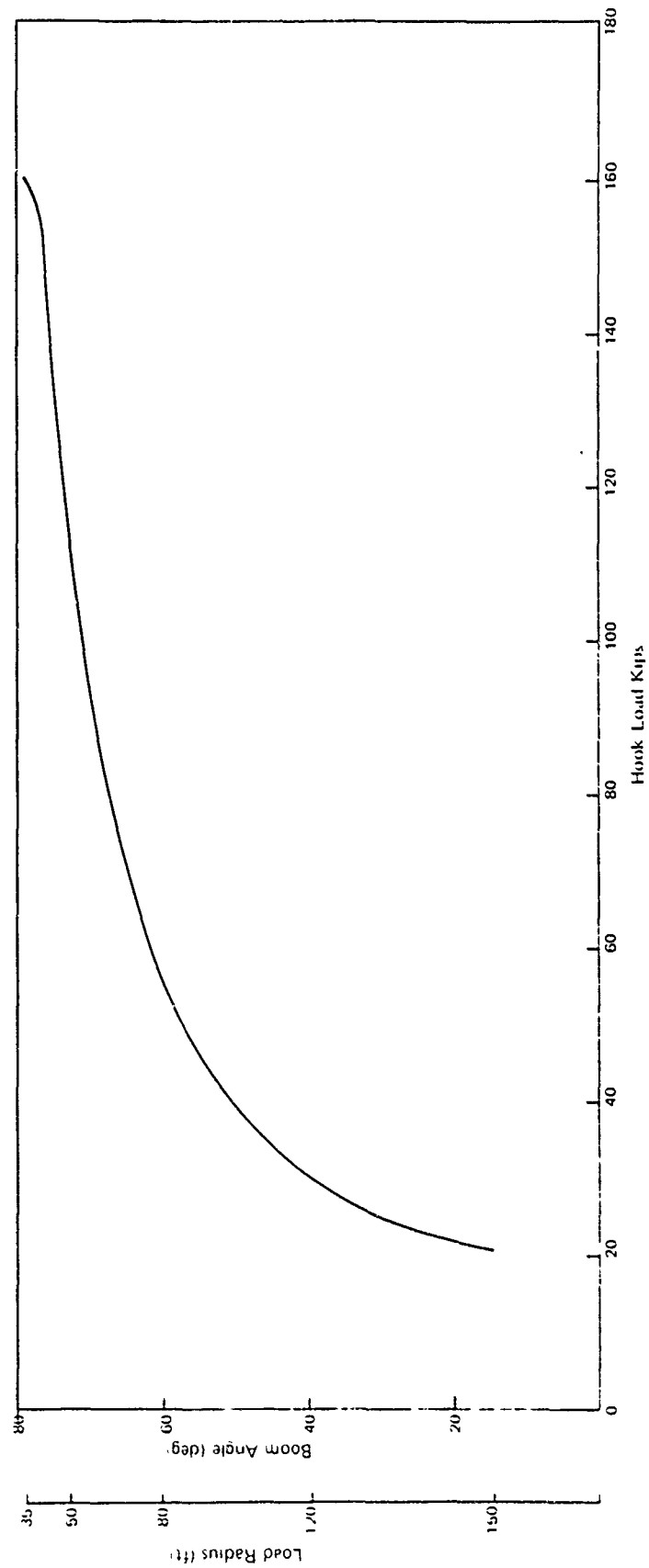
Figure 3.   A Static Load Rating Curve for the P&H 6250-TC.

Table 1. Physical and Environmental Conditions
For the TCDF and COD Concepts

Condition	TCDF	COD
Platform	FDL-B FDL-A	C4
Sea State	2 3	2 3
Wave direction	Quartering	Quartering
Wind conditions	$7.34 \sqrt{H_{1/3}}$ knots	$7.34 \sqrt{H_{1/3}}$ knots
Operating sector	180°	180°
Operating radius	150' preferred 110' acceptable	50'

Table 2. Crane Off-loading Conditions

Container off loading rate	250 containers/20 hr day/crane
Average duty cycle	13 lifts/hour
Average crane cycle	4.8 minutes/lift
Average hook load duration	2.5 minutes/lift
Prolonged service periods	6 months and 12 months
Component weights	

Component	Component Weight	
	Average (LT)	Maximum (LT)
8 x 8 x 20 ISO container	15	20
8 x 8 x 40 ISO container	21	30
Load handling accessories[1]	5	5

Probable weight of lift

Probability (%)	Weight of lift				Number of Containers		
	Range (LT)		Average (LT)		Daily Total	Shipment Total	
	20' Container	40' Container	20' Container	40' Container		20' Container	40' Container
Standard Shipments							
10	18-25	27-35	22	31	25	140	70
15	14-18	21-27	16	24	38	210	105
10	12-14	18-21	13	19	25	140	70
65	5-12	5-18	9	11	162	910	455
Special Ammunition Shipments							
100	25	NA	25	NA	250	1,400	NA

[1] Hook block, slings, and all other handling accessories.

Table 3. Example Output From the Wisconsin Crane Boom Analysis Program

SIMULATION OF 1179 CLASS LST FOR LHEAD=2 AND H13=2.5 FT.

THETA	VRPL	H(1/3)	LHEAD
55.0	80.0	5.0	3

THE SUSPENDED WEIGHT   W   50.00   (KIPS)

THE STRUCTURE ROTATION ANGLE BETA   0.0

THE RESPONSE STATISTICS MATRIX (STM)

	XMIN	XM-SD	XMEAN	STD DEV	XM+SD	XMAX
1	-.32	-.14	-.00	.13	.13	.32
2	-2.05	-.78	.00	.78	.78	1.83
3	-11.08	-4.81	.05	4.87	4.92	10.85
4	-1.30	-.51	-.00	.50	.50	1.21
5	-2.52	-.98	-.00	.98	.98	2.44
6	-7.94	-7.79	.17	7.96	8.13	9.09
7	-.77	-1.86	-.00	.1.85	1.85	.83
8	-1.89	-1.50	-.01	1.49	1.48	1.89
9	-5.11	-4.93	.10	5.04	5.14	5.00
N	.85	.29D+01	.60D+01	.31D+01	.91D+01	14.52

THE DYNAMIC LOAD FACTORS MATRIX (DLF)

	DMIN	DM-SD	DMEAN	STD DEV	DM+SD	DMAX
1	.06	.03	.00	.03	.03	.06
2	2.01	.76	.00	.76	.76	1.79
3	5.39	2.34	.03	2.37	2.39	5.28
4	.99	.39	.00	.38	.38	.92
5	2.55	1.00	.00	1.00	.99	2.47
6	142.58	139.89	3.10	142.99	146.09	163.25
7	1.18	2.83	.00	2.83	2.82	1.27
8	3.83	3.04	.02	3.01	2.99	3.83
9	299.06	288.53	6.06	294.59	300.65	292.64

THE DYNAMIC LOADS MATRIX (PD)

	PDMIN	PM-SD	PDMEAN	STD DEV	PM+SD	PDMAX
1	-.67	-.27	.00	.27	.27	.75
2	-948.41	-425.89	2.30	428.19	430.50	881.28
3	-5.80	-2.04	.01	2.04	2.05	8.68
4	-1237.90	-578.02	-1.92	576.10	574.17	1327.01
5	-2222.31	-1057.55	-4.35	1053.20	1048.85	2402.71
6	-450.47	-495.34	-8.65	486.69	478.03	497.79
7	-6522.72	-4872.76	-34.94	4837.82	4802.88	6901.55
8	-9363.48	-10366.27	-77.90	10288.37	10210.47	9887.99
9	-2164.40	-2099.15	40.93	2140.08	2181.01	2040.98
N	.97D+02	.13D+04	.45D+04	.32D+04	.77D+04	.12D+05

Table 4. Characteristics of the Analyzed Machine

Model	P&H 6250 TC
Boom	94 x 94 Basic 70 ft with 30' container tip
	Insert 30 ft
	Insert 50 ft
	Total 150 ft
Counter weight	92,560 lb
Rating	Over the side and rear
Outriggers	Fully extended

Table 5. Location of Failure Points in the Boom

P&H 6250 94 x 94 Boom Scale: 1 in. = 30 ft															Failure Condition Parameters				
40 Ft Base			30 Ft Insert			50 Ft Insert						30 Ft Tip (Container)			$H_{1/3}$ (ft)	Sea Dir*	Rotation Angle (deg)	Load (LT)	Rope Length (ft)
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O					
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•					
				•		•			•			•			2.5	B	0	10	80
				•		•			•			•			2.5	B	0	20	190
				•		•			•			•			5.0	Q	0	10	190
				•		•			•			•			5.0	B	0	10	190
		•		•		•			•					•	5.0	B	45	10	190
				•				•			•			•	5.0	B	90	10	190
			•	•		•			•			•		•	5.0	Q	0	20	190
				•		•			•			•			5.0	Q	45	20	190
				•		•			•			•			5.0	Q	90	20	190
			•	•		•									5.0	B	0	20	190
•					•			•			•				5.0	B	45	20	190
	•							•			•			•	5.0	B	90	20	190

* B = Bow, Q = Quartering.

Table 6. Equivalent Static Load Analysis, Maximum Results

Significant Wave Height (ft)	Vertical Rope Length (ft)	Sea Direction	Hook Load (kips) 10 LT	Hook Load (kips) 20 LT	Crane Rotation Angle (deg)	Side Load (kips) 10 LT	Side Load (kips) 20 LT	Chord Stress (%) 10 LT	Chord Stress (%) 20 LT	Side Lacing Stress (%) 10 LT	Side Lacing Stress (%) 20 LT	Top and Bottom Lacing Stress (%) 10 LT	Top and Bottom Lacing Stress (%) 20 LT	Out of Plane Tip Deflection (in.) 10 LT	Out of Plane Tip Deflection (in.) 20 LT
2.5	80.3	bow	20.8	15.2	0	0.6	0.6	20	10	10	10	2	2	1.0	1.0
					45	1.2	1.1	20	10	10	10	5	4	2.2	1.8
					90	1.2	1.0	20	10	10	10	5	4	2.1	1.8
2.5	80.3	quarter	34.0	—	0	3.3	—	40	—	11	—	14	—	5.9	—
					45	1.2	—	30	—	11	—	5	—	2.2	—
					90	1.4	—	30	—	11	—	6	—	2.4	—
2.5	80.3	beam	49.7	—	0	92.7	—	340	—	9	—	393	—	?	—
					45	6.1	—	50	—	12	—	26	—	11.1	—
					90	1.7	—	40	—	11	—	7	—	3.1	—
2.5	190.0	quarter	29.1	29.1	0	—	3.3	—	30	—	11	—	13	—	5.8
					45	—	1.7	—	20	—	11	—	7	—	3.0
					90	—	1.8	—	22	—	11	—	7	—	3.2
2.5	190.0	beam	52.4	52.4	0	—	92.0	—	330	—	10	—	391	?	?
					45	—	5.6	—	50	—	12	—	24	—	10.1
					90	—	2.2	—	30	—	11	—	9	—	4.0
5.0	190.0	bow	67.0	138.4	0	0.7	0.9	50	60	14	20	3	40	1.3	1.8
					45	2.2	5.6	60	80	14	16	10	28	4.2	11.6
					90	2.1	5.3	60	80	14	16	9	26	4.0	10.9
5.0	190.0	*quarter*	*143.0*	*262.5*	*0*	*60.3*	*10.3*	*330*	*150*	*15*	*26*	*316*	*71*	*?*	*26.8*
					45	*2.4*	*14.2*	*100*	*170*	*10*	*8*	*12*	*101*	*4.9*	*37.1*
					90	*3.6*	*110.7*	*100*	*500*	*19*	*23*	*18*	*599*	*7.4*	*?*
5.0	190.0	*beam*	*235.9*	*246.8*	*0*	*184.2*	*183.4*	*1,020*	*990*	*25*	*26*	*1,211*	*1,243*	*?*	*?*
					45	*11.5*	*2.5*	*240*	*250*	*87*	*109*	*74*	*16*	*28.5*	*6.2*
					90	*3.6*	*12.2*	*920*	*970*	*1,375*	*417*	*23*	*80*	*9.0*	*30.7*

Appendix E

DYNAMIC VERTICAL FORCES ON A CRANE
LOADING (UNLOADING) A FLOATING PLATFORM

by

Carley C. Ward

September 1976

PREFACE

Operational Requirement (OR-YSL03) for the Container Off-Loading and Transfer System (COTS) addresses the need for an integrated cargo handling system for discharging non-self-sustaining container-capable ships and other ships and barges at open beach sites and identifies the Navy's responsibility for developing certain elements of the required overall cargo handling system. DOD policy is documented in the DOD Project Master Plan for Surface Container Supported Distribution and the DOD system definition paper "Over-the-Shore Discharge of Container-ships (OSDOC) System."

The Navy's version of the container distribution elements constitute the Container Off-Loading and Transfer System (COTS). The COTS advanced development program includes (a) the ship unloading subsystem, (b) the ship-to-shore subsystem, and (c) system level elements. The ship un-- loading subsystem includes: (a) ship/barge candidates, (b) cranes, (c) crane integration with ships/barges and (d) moorings. This report addresses the progress and accomplishments associated with the crane element of the ship unloading subsystem.

CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

Marine cranes operate in the demanding and ever changing dynamic environment imposed by the sea. Some of the most severe loads occur when the crane is ship mounted and is on/off loading an adjacent barge or ship. The wave induced relative motion between the crane and the load, as the load leaves the barge platform, can produce severe dynamic stresses in the crane boom. The lifting line can become slack and then suddenly taut. But even with a continuous load in the hoist line, just the transfer of load from the moving platform to the crane will produce oscillations in the load. It is these oscillations which are treated in this paper.

The dynamic forces on marine cranes have been computed in Ref (1,2). In these references, forces produced by the initial relative velocity between the hook and the load are computed, but the force due to the weight of the load is assumed to be static or constant. Using this assumption the static and dynamic loads were added to find the derating factor. Unfortunately the load is not static. In operation the load is transferred from the deck to the crane and the force on the crane due to the weight of the load varies with time.

In the following analysis the response caused by the application of the load weight is determined. The effects of deck and hoist relative velocity are also included. Then using vector addition the combined dynamic force is computed. Finally, the results are related to wave characteristics so that derating charts can be developed similar to those in Reference (1).

ANALYSIS

The objective of this study is to find the dynamic forces on a marine crane caused by lifting a load from, or setting a load on, a moving deck.

Although the crane support and load platform are rotating in inertial space the effect of rotation will be neglected in order to simplify the equations. The concept being presented is difficult to grasp and needs to be presented in its simplest form. The rotational effect can and should be added eventually by rewriting the equations in three dimensions and using transformation matrices to convert to the crane coordinate system. However in this preliminary study, the crane and platform are assumed to be moving the load only in the vertical direction (refer to Figure 1).
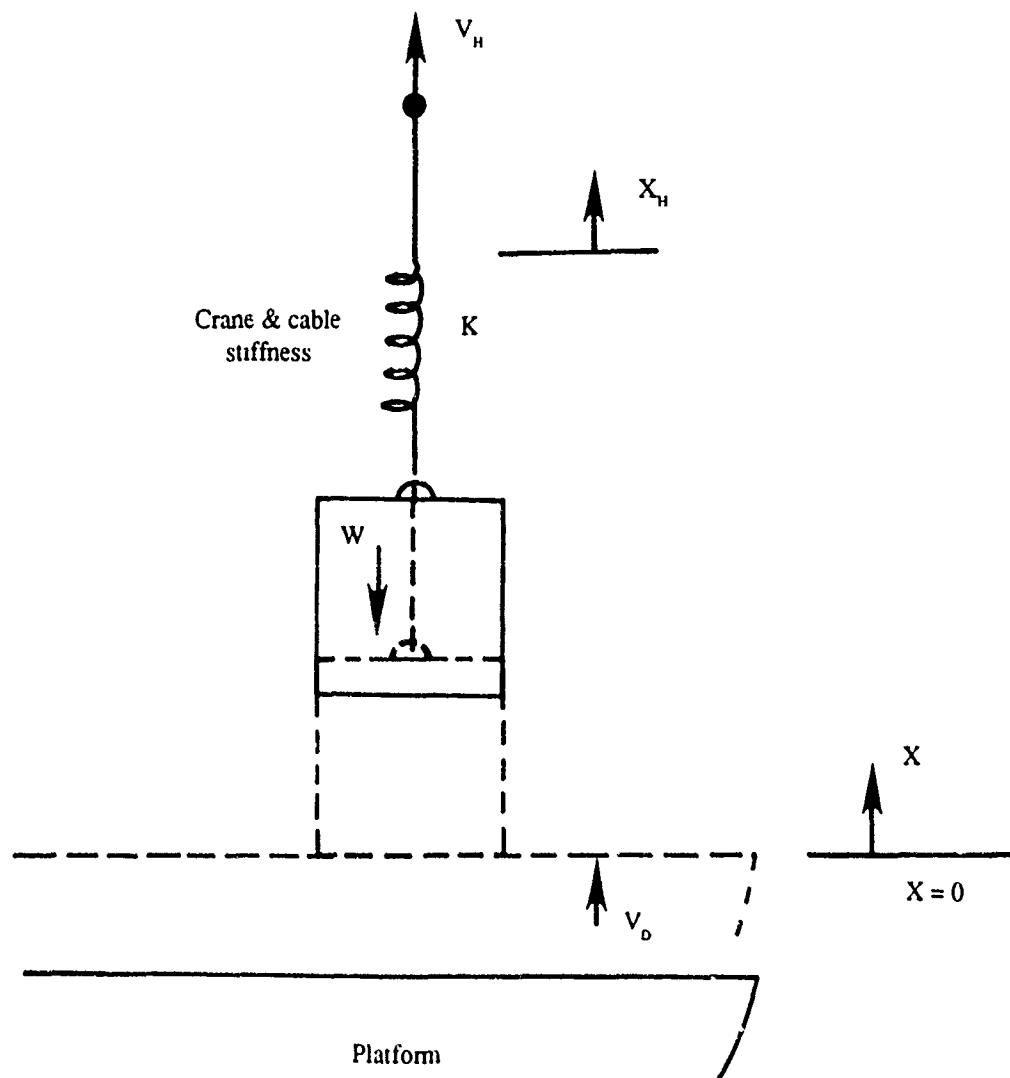
Figure 1. Dynamic system.

The other simplifying assumptions are the following: (a) stiffness of the combined structural system (crane boom, suspension lines and hoisting line) is represented by a single vertical spring stiffness. The mass of the lines and boom are neglected using this assumption. (b) This structural stiffness does not change in the short time interval being studied. (c) The vertical motion of the platform follows the wave. (d) Damping is neglected. (e) The system is linear.

The solution separates into three parts: (1) The determination of the conditions when the load leaves the deck, (2) The solution of the dynamic equation of motion, and (3) the calculation of dynamic forces. The Laplace transform method is used to solve the differential equation of motion.

Derivation of Separation Conditions

Before the crane hook contacts the load, the weight of the load and the inertia force due to deck acceleration are reacted only by the deck or load platform. Refer to Figure 2. If the load is being accelerated up by the wave action the equation for the deck force F_D is

$$F_D = -MA_D - W \tag{1}$$

where A_D is the acceleration of the deck. When the crane hook is attached to the weight but before the load leaves the deck the equation becomes

$$F_D = -W - MA_D + F_C \tag{2}$$

These conditions are shown in Figure 2. The load supported by the crane is equal to the elastic deformation of the structure, u, multiplied by its stiffness K

$$F_C = -Ku \tag{3}$$

(for a positive F_C, u is negative according to the sign convention in Figure 2),

Rewriting Equation 2

$$F_D = -W - MA_D - Ku \tag{4}$$

When $F_D = 0$

$$Ku = -W - MA_D \tag{5}$$

the load lifts off the deck. Note that at lift off the load in the crane line is NOT equal to W but equal to W plus another quantity which is a function of sea state. The force in the cable would only be equal to W if the load were stationary. The force necessary to lift the weight off the deck is analogous to picking an object in
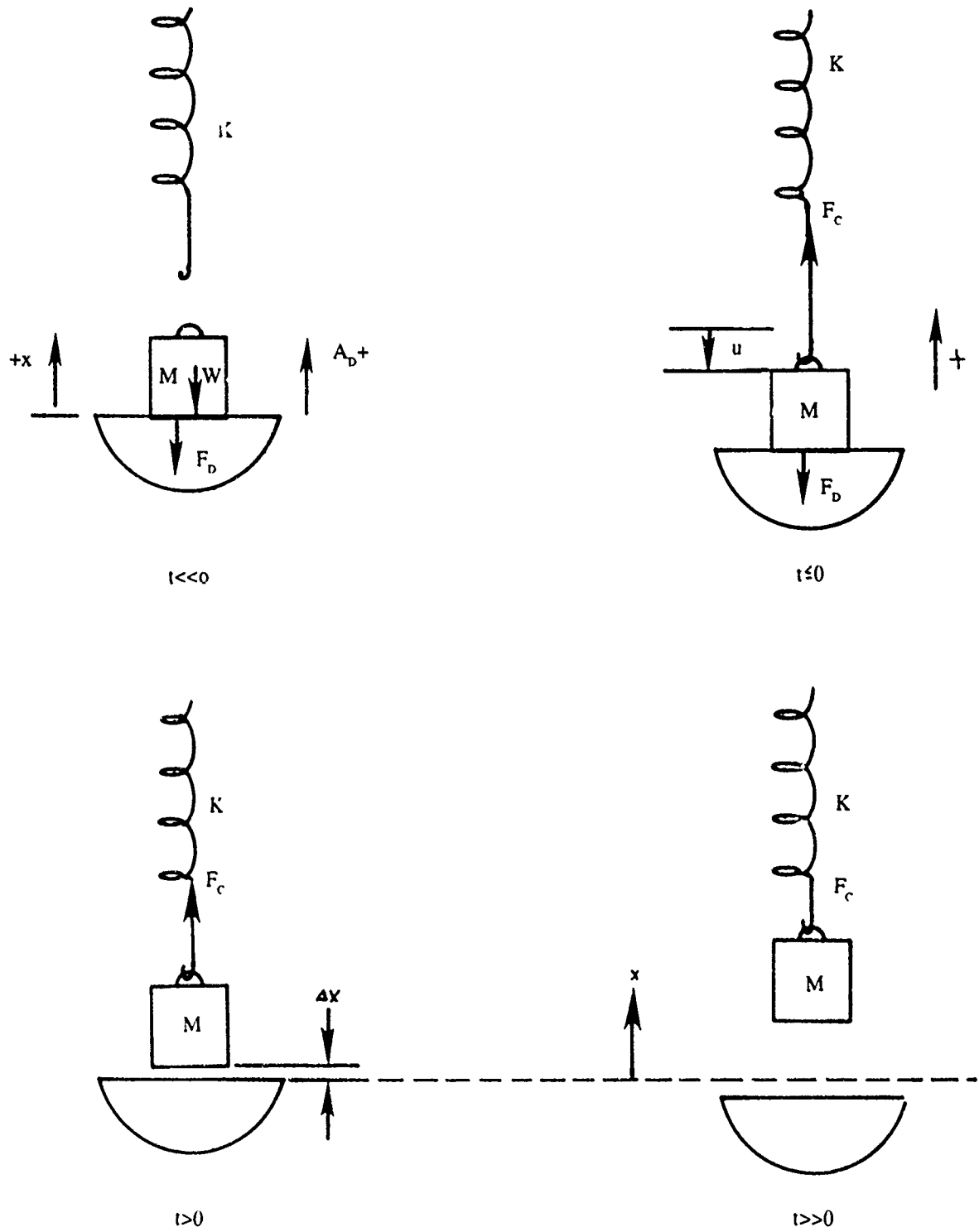
Figure 2. Load separating from the deck at t = 0.

an accelerating elevation. If the elevator is accelerating in the upward direction the object feels heavier. When the elevator is accelerating down the reverse is true; the object is lighter. However, the crane motion is independent of the load acceleration and as the load clears the deck the load on the crane hook becomes W. Thus, a step change in force occurs as the load separates from the deck. The magnitude of the step being MA_D, the sign is defined by the direction of deck acceleration, A_D. The equation for the force at the hook is as follows:

$$f(w)_o = +W + MA_D \qquad \text{at } t = 0$$

$$f(w)_\Delta = W \qquad \text{at } t = \Delta t \tag{6}$$

Figure 3 shows step forces for several possible situations. Based on Equation 6 the worst condition would occur when the deck dropped out from under the load at an acceleration equal to the acceleration of gravity, g (i.e., $A_D = -g$). The resulting step force on the crane would go from 0 to W at lift off. Actually the deck could not drop with an acceleration equal to g. This is a ''worst-case'' condition, and is representiative of what would occur if the load slipped laterally off the ship deck before the hoist line elongated.

Solution of the Equation of Motion

At t = 0 the load lifts off the deck and a single differential equation can be used to describe the motion of the load.

$$M\ddot{x}_L + K(x_L - x_H) = -f(w) \tag{7}$$

x_L and $\ddot{x}_L$ the load displacement and acceleration are measured relative to inertial space. $x_L - x_H$ is the elastic displacement of system after time t = 0. f(w) is the forcing function due to the weight. The displacement component due to line and crane motion, x_H, shown in Figure 1, is obtained by integrating

$$x_H = \int_0^t \dot{x}_H \, dt \tag{8}$$

If $\dot{x}_H$ is not a constant it can be computed from $\ddot{x}_H$.

$$\dot{x}_H = \int_0^t \ddot{x}_H \, dt + \dot{x}_{Ho} \tag{9}$$

Function dependent
on wave motion

W

MA_D

t = 0

MA_D

t = 0

Deck accelerating
down

Deck accelerating
up

$W - M\left|A_d\right| \text{ to } W$

$W + M\left|A_d\right| \text{ to } W$

W

t = 0

t = 0

Deck does not
accelerate

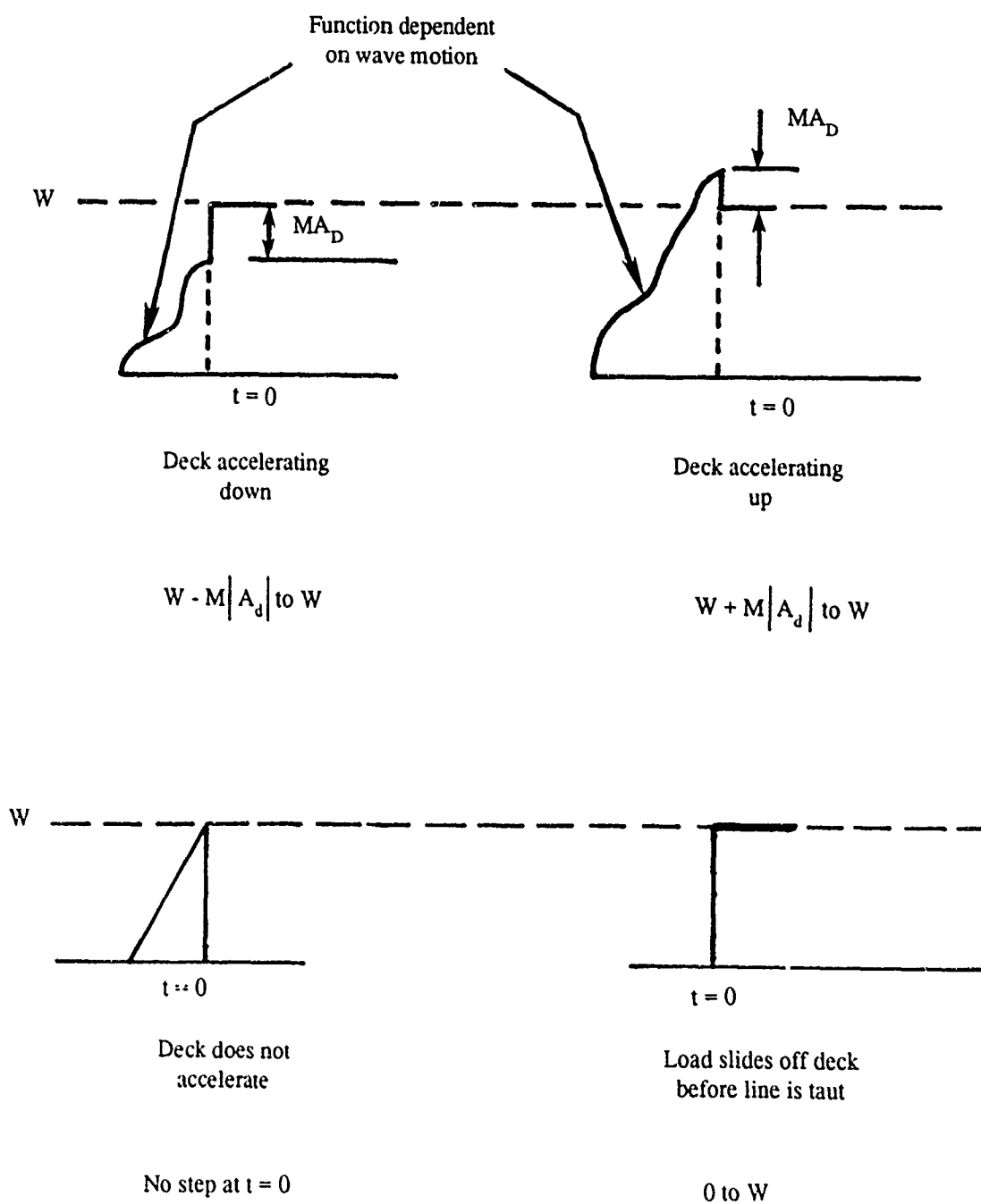Load slides off deck
before line is taut

No step at t = 0

0 to W

Figure 3. Step force at the crane hook due to transferring the weight, W,
from the deck to the crane, f(W).

The initial displacements are

$$x_o = x_L = u \qquad x_H = 0 \qquad \text{at } t = 0$$

Rewriting Equation 7 so that the known forces are on the right side

$$M\ddot{x}_L + Kx_L = +Kx_H - f(w) \tag{10}$$

To simplify the solution a new reference x is used for the load displacement.

$$x = x_L - u \tag{11}$$

By subtracting Equation 5 from Equation 10 the static force is subtracted out of the differential equation of motion.

$$M\ddot{x}_L + K(x_L - u) = Kx_H - f(w) + W + MA_D \tag{12}$$

Because $-W - MA_D = f(w)_o$ (the step value at $t < 0$), and x_L is independent of the coordinate reference change, Equation 12 can be written in terms of the new coordinate x as

$$M\ddot{x} + Kx = Kx_H - f(w) + f(w)_o \tag{13}$$

using Equation 6

$$-f(w) + f(w)_o = +MA_D \qquad \text{(step function)} \tag{14}$$

the sign convention for A_D is
+ deck accelerating up
- deck accelerating down

The Laplace Transform of Equation 13 is

$$M[s^2\bar{X}(S) - SX(0) - X'(0)] + K\bar{X}(S) = \bar{F}_1(s) + \bar{F}_2(s) \tag{15}$$

where $\quad X(0) = x_o = 0$

$X'(\ ) = \dot{x}_{L_o} = V_{D_o}$ the deck velocity at $t = 0$

$\bar{F}_1(s) = $ Laplace transform of $K \int \dot{x}_H \, dt$

$\bar{F}_2(s) = $ Laplace transform of step $+ MA_D$

The support velocity $\dot{x}_H$ depends on the main hoist line speed and the motion of the crane support. To simplify the solution the support velocity is assumed constant. That is, the crane support is not accelerating as the load is lifted from the deck. For this case

$$\bar{F}_1(s) = KV_Ht = KV_H/S^2$$

$$\bar{F}_2(s) = (+MA_D) = +MA_D/S \qquad (16)$$

Rewriting Equation 15

$$(MS^2 + K)\bar{X}(s) = MV_D - \frac{KV_H}{S^2} + \frac{MA_D}{S} \qquad (17)$$

Dividing Equation 15 by $MS^2 + K$

$$x(s) = \frac{MV_D}{MS^2 + K} - \frac{KV_H}{S^2(MS^2 + K)} + \frac{MA_D}{S(MS^2 + K)} \qquad (18)$$

Taking the inverse Laplace transform to find the displacement x and substituting β for $\sqrt{K/M}$

$$x = \frac{V_D \sin \beta t}{\beta} + \frac{V_H}{\beta}(\beta t - \sin \beta t) + \frac{A_D}{\beta^2}(1 - \cos \beta t) \qquad (19)$$

Calculation of Dynamic Forces

The force on the crane is the elastic deformation, $x_L - x_H$, multiplied by the stiffness. The crane force as a function of the variable x from equation (11) is

$$F_C = Kx - Kx_H + Ku \qquad (20)$$

Substituting Equation 5 and 19 into Equation 20 yields

$$F_C = \frac{K}{\beta}\left[V_D \sin \beta t - V_H \sin \beta t + \frac{A_D}{\beta}(1 - \cos \beta t)\right] - W - MA_D \qquad (21)$$

Simplifying Equation 21

$$F_C = \frac{K}{\beta}(V_D - V_H) \sin \beta t - MA_D \cos \beta t - W \qquad (21a)$$

If the deck is accelerating downward A_D is negative changing the sign of the cos term, and Equation 21a becomes

$$F_C = \frac{K}{\beta}(V_D - V_H) \sin \beta t + M|A_D| \cos \beta t - W \qquad (21b)$$

dividing by W, Equation 21a becomes

$$\frac{F_C}{W} = \frac{K}{W} \frac{(V_D - V_H)}{\beta} \sin \beta t - \frac{A_D}{g} \cos \beta t - 1 \qquad (22)$$

If separation occurs as the deck is moving down with a velocity $- V_D$ as in Reference 1, Equations 22a become

$$\frac{F_C}{W} = -\frac{K}{W} \frac{(V_D + V_H)}{\beta} \sin \beta t - \frac{A_D}{g} \cos \beta t - 1 \qquad (23)$$

If the A_D term were neglected the equation would be the same as that in References (1 and 2) except for a difference in sign convention. Vector addition can be used to combine the sin and cos terms and it can be shown that the maximum dynamic force is independent of the direction of the deck acceleration A_D. The deck acceleration only establishes a phase relationship (Refer to Figure 4). The load on the crane is obtained directly from Equation 23 by substituting in the values for V_D and A_D at t = 0, and the value for the hoist velocity, V_H. The maximum force on the crane is

$$F_{C^{max}} = -W \left[\frac{1}{g} \frac{K}{W} (V_D + V_H)^2 + \frac{A_D^2}{g^2} \right]^{1/2} - W \qquad (24)$$

The terms within the square root parentheses are the dynamic force terms. In the first dynamic force term the quantity K/W appears. This term is directly related to the stiffness and if the crane were strengthened this term would increase. Actually

$$K/W = 1/static\ displacement$$

As the static deflection approaches 0 the dynamic loads become more severe. The second dynamic force term has the quantity A_D/g. The magnitude of this term may be easily established by comparing deck accelerations to the acceleration of gravity.

Special Cases

Case 1. Setting the Load on the Deck. If the load is being set on the deck, and due to wave action the deck drops out from under the load before the load is off the crane, the force computations are the same as above. Equation 7 holds whether the load is moving up or down. The load is transferred to the crane as in Equation 5 when $F_D = 0$.
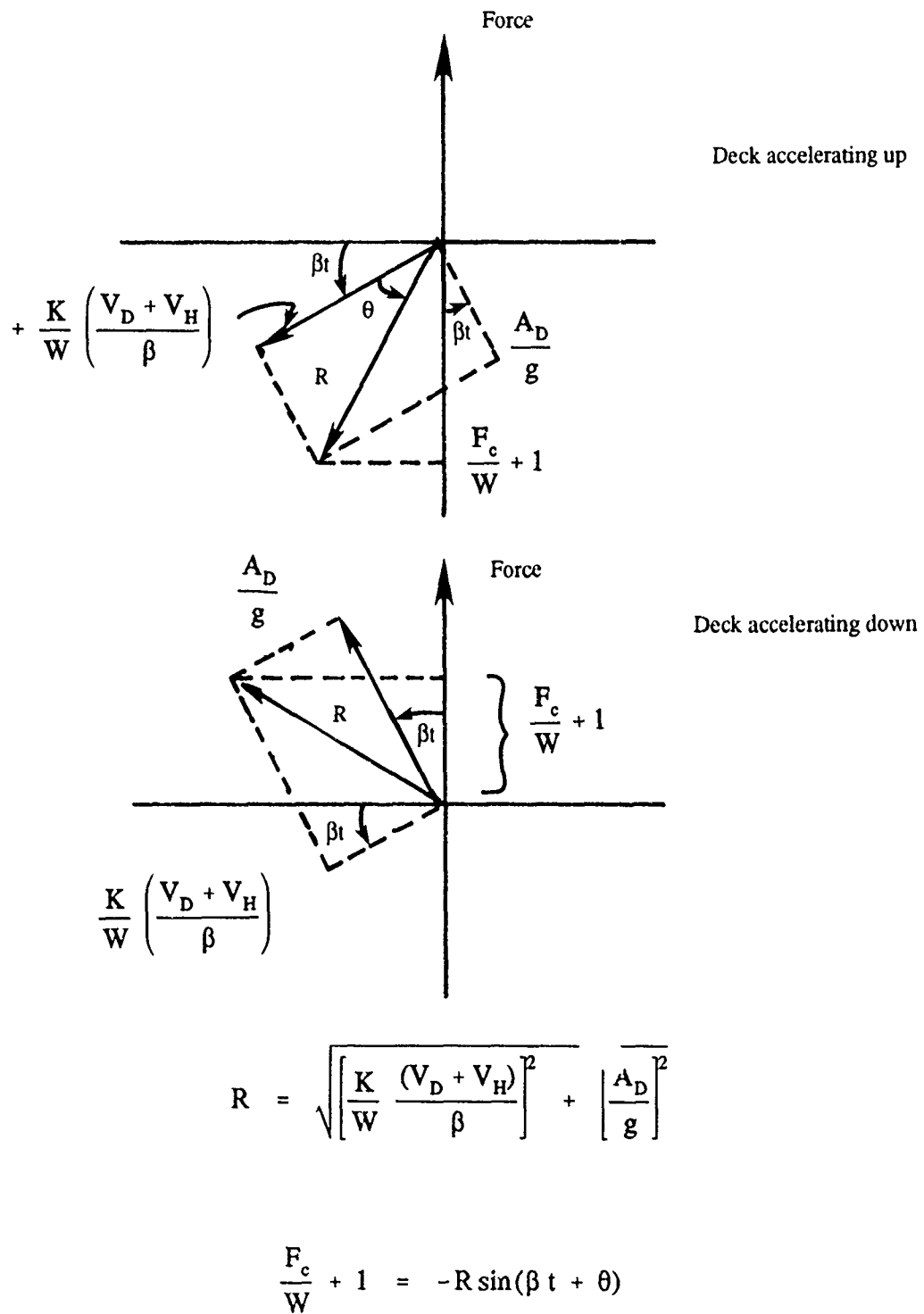
Figure 4. Phase relationship between oscillating components of F.

Case 2. Harmonic Wave Motion. Harmonic motion could be assumed as in
Reference (1) to characterize a sea state. However in harmonic motion
A_D is usually low and such an analysis would not be conservative. Using
the quantities H and T, where H is peak to through amplitude and T is
the period of the wave, the following relationships exist

$$V_D = \frac{\pi H}{T} \sin\left(\frac{2\pi}{T} t + \phi\right)$$

$$A_D = \frac{2\pi^2 H}{T^2} \cos\left(\frac{2\pi}{T} t + \phi\right)$$

to clear the wave $V_H = \frac{2}{3}\frac{H}{T}$

The above quantities can be substituted into Equation 24 to compute the
force on the crane, F_C.

Case 3. Random Wave Motion. A better approach would be to substitute into
Equation 24, measured accelerations and velocities. Some worst possible
conditions should be selected. The vertical deck acceleration and velocity
components obtained from the angular acceleration and velocity of the ship
need to be included. A probability approach, that of selecting deck
accelerations and velocities which would include a large percentage of
situations, could also be used.

CONCLUSIONS

A systematic set of equations have been developed for on/off loading
forces on a marine crane. The equations though simple in appearance can
be easily expanded to include hoist accelerations and rotational effects.
They can be combined with structural system equations to complete the
crane dynamic analysis.

Dynamic forc   lop because the load oscillates. These oscillations
are caused by: (1) the initial relative velocity between the hook and
the load and (2) the transfer of the load from the deck to the crane. The
latter oscillations, those due to load transfer, have been overlooked in
previous analysis (references 1 and 2).

The equations show that deck velocity and deck acceleration at load
lift off influence the dynamic forces on the crane. Raising the crane
stiffness factor by making it stronger would increase the dynamic load.
Wave action such as sea chop which increases instantaneous deck accelerations
can critically affect the dynamic forces.

A precise description of the acceleration and velocity of the deck
is needed. Then using representative hoisting velocities, reliable estimates
of the dynamic loads can be obtained. Eventually the dynamic characteristics
of the boom and suspension line need to be simulated in three dimensions, so
that out of plane loads can be investigated.

REFERENCES

1. K. Johnson, Theoretical Overload Factor Effect of Sea State on Marine Cranes, Offshore Technology Conference, Paper 2584.

2. D. E. Charrett, Dynamic Factors for Offshore Cranes, Offshore Technology Conference, Paper 2578.

LIST OF SYMBOLS

A_D	Acceleration of the deck at time t = 0
$\bar{F}(s)$	Laplace transform of forcing functions
F_D	Force on the deck
F_C	Force on crane
$f(w)$	Step forcing function due to the transfer of the load
g	Acceleration of gravity
H	Wave height peak to trough
K	Structural stiffness
$\mathcal{L}$	Laplace transform
M	Mass of load
S	Laplace operator
T	Wave period
t	Time
u	Elastic deformation of structure
V_H	Constant hoist velocity
V_D	Velocity of deck at t = 0
W	Weight of the load
$\bar{X}$	Laplace variable
$X(0)$, $X'(0)$	Initial position and velocity in Laplace Equation
x_L	Position of load in inertial space
x	$x_L - u$
x_H	Support position

$\ddot{x}_L$ Acceleration of load in inertial space

$\dot{x}_H$ Support velocity

$\ddot{x}_H$ Support acceleration

β $\sqrt{K/M}$

θ Phase angle

ϕ Wave phase angle

SUBSCRIPTS

o   initial condition

Δ Condition at Δt

Appendix F

DYNAMIC LOADS ON A SHIPBOARD CRANE BOOM
DUE TO SHIP MOTION

by

Carley C. Ward and Frank R. Johnson, Jr.

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PREFACE

Operational Requirement (OR-YSL03) for he Container Off-Loading
an4 Transfer System (COTS) addresses the need for an integrated cargo
handling system for discharging non-self-sustaining container-capable
ships and other ships and barges at open beach sites and identifies the
Navy's responsibility for developing certain elements of the required
overall cargo handling system. DOD policy is documented in the DOD
Project Master Plan for Surface Container Supported Distribution and
the DOD system definition paper "Over-the-Shore Discharge of Container-
ships (OSDOC) System."

The Navy's version of the container distribution elements constitute
the Container Off-Loading and Transfer System (COTS). The COTS advanced
development program includes (a) the ship unloading subsystem, (b) the
ship-to-shore subsystem, and (c) system level elements. The ship un-
loading subsystem includes: (a) ship/barge candidates, (b) cranes,
(c) crane integration with ships/barges and (d) moorings. This report
addresses the progress and accomplishments associated with the crane
element of the ship unloading subsystem.

ABSTRACT

Motion of the ship produces dynamic loads in a ship-mounted crane boom. Nonlinear equations for determining these loads are developed using vector analysis and rotating coordinate frames. Once computed, the load functions are incorporated into the flexible boom matrix equation of motion. The elastic response of the boom to these time varying inertial loads can then be computed.

INTRODUCTION

Ship-mounted cranes operate in a demanding dynamic environment: the angle between the boom centerline and direction of gravity is ever changing, and the lifted load and boom are subjected to time-varying accelerations and velocities. The additional motion-induced stresses in the boom could produce a structural failure, if they were not considered in float-rating the crane. This stress state is also aggravated by the overlapping frequency range of the ship motion and boom vibration modes. The dynamic stresses would be amplified should the long flexible boom response couple with the oscillating ship motion. A structural analysis of the crane boom is required to determine the magnitude of these ship-motion-induced stresses and to investigate possible coupling. Anticipated critical operating conditions need to be simulated, and the stresses along the boom computed as a function of time.

A method is presented herein for determining these dynamic stresses in the boom.* The procedure follows the displacement

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*This method has been previously employed in head injury research to simulate the motion of the head and compute stresses in the brain (Ref 1).

References and illustrations at end of paper.

formulation used in linear structural analyses, with the basic dif-
ference being additional terms on the right side of the equation of
motion. These terms, called inertial loads, are functions of the boom
acceleration and velocity in inertial space. This paper focuses primari-
ly on the derivation of these ship motion functions. General vector
equations applicable to any structure in rotating coordinates are employed.
A specific case is considered to demonstrate the technique. Because the
general form of the equation of motion is unchanged, existing structural
analysis computer programs can be easily modified to include these
terms.

The dynamic stresses produced by the crane operator swinging the
load can be included with these equations, but the forces produced by
load pendulation (swing of the load relative to the boom) can not. The
equations become nonlinear when pendulation is included, thereby requir-
ing a nonlinear computer program. To maintain linearity, pendulation is
not included, and the mass of the lifted loads is concentrated at the
tip of the boom. However, pendulation should be included in a subsequent
nonlinear analysis where procedures for controlling the motion of the
lifted load can also be investigated.

SOLUTION PROCEDURE

A solution procedure was developed for computing the response of
the rotating/translating crane boom (Figs. 1 and 2). Following this
procedure, equations were generated that could be solved using general
purpose structural analysis programs. Other procedures could be fol-
lowed, but they would require special programming and additional data
handling.

The unique aspect of the procedure relates to the calculation and
inclusion of ship-induced inertial accelerations. The procedure is
completely general; the crane can be located anywhere on the ship and

the boom can be oriented at any angle or be in motion. The angles or rotations of the boom can be large relative to inertial space. Small angle restrictions are unnecessary, because the nonlinear quantities involving the angles are known. Linearity is preserved by including these known terms on the right side of the equation of motion. Only displacement of the boom nodes relative to the instantaneous axis of the boom is assumed to be small.

The customary assumptions (those associated with beam theory and linear elasticity) are made in developing the structural model. In addition, it is assumed that support lines for the boom never become slack. The boom structure may be modeled, member by member, using finite elements, or with equivalent beam elements along the boom center-line.

EQUATION DERIVATION

Equation of Motion Using Newton's Law. The boom is first dis-cretized into a system of finite elements or equivalent beams with lumped masses located at the nodes. The linear matrix equation of motion for the structural system can be derived from the equilibrium equations for each node using Newton's second law of motion. The result-ing matrix equation can be written:

$$M\ddot{U} + KU = F \quad \ldots \ldots \ldots \ldots \ldots \ldots [1]$$

where U and $\ddot{U}$ are the nodal displacements and nodal accelerations rela-tive to inertial space. F is the matrix of generalized loads or forces acting on the boom. M and K are the diagonal lumped mass matrix and the stiffness matrix, respectively, generated by the structural analysis program. Because the boom may experience large rotations and displace-ments relative to inertial space, Eq. 1 is converted to boom-fixed coordinates to preserve accuracy. This is accomplished by separating the terms in U and $\ddot{U}$ so that

$$U = X + Q \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad [2]$$

$$\text{and} \quad \ddot{U} = \ddot{X} + \ddot{Q} \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad [3]$$

where X and $\ddot{X}$ are the displacements and accelerations relative to the boom-fixed axis, and Q and $\ddot{Q}$ are the displacements and accelerations of the boom relative to inertial space. Substituting Eqs. 2 and 3 into Eq. 1 provides

$$M\ddot{Q} + KQ + M\ddot{X} + KX = F \quad \ldots \ldots \ldots \quad [4]$$

Since there is no strain in rigid-body displacements,

$$KQ = 0 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad [5]$$

and Eq. 4 can be rewritten

$$M\ddot{X} + KX = F - M\ddot{Q} \quad \ldots \ldots \ldots \ldots \quad [6]$$

It is important to note that the form of Eq. 6 is the same as that of equations commonly used in structural analysis, except for the additional matrix $M\ddot{Q}$. Fortunately, in this analysis, $\ddot{Q}$ is independent of X when second-order terms are neglected. Once $\ddot{Q}$ is computed, $M\ddot{Q}$ can be combined with F and treated as a time-varying applied load. Eq. 6 can then be solved using standard structural analysis techniques and existing computer programs.

Computation of Inertial Loads ($M\ddot{Q}$). The position vectors of each node are differentiated twice with respect to inertial space to compute $\ddot{U}$. Then $\ddot{Q}$ is obtained from the relationship

$$\ddot{Q} = \ddot{U} - \ddot{X} \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad [7]$$

Refer to Eq. 3.

    (a) Form of $\ddot{U}$ Matrix. U is written in terms of position vectors

$$U = \begin{Bmatrix} OP_1 \\ OP_2 \\ OP_3 \\ \vdots \\ OP_n \end{Bmatrix} \text{in boom coordinates} \qquad \cdots \cdots \cdots [8]$$

where the position vectors are defined in terms of their end points: P_1 through P_n are node points 1 through n in the boom, and 0 is the origin of the inertial frame, as shown in Figs. 1 and 3.

U is differentiated twice to obtain $\ddot{U}$:

$$\ddot{U} = \frac{^Nd}{dt}\left(\frac{^Nd}{dt}U\right) = \left[\frac{^Nd}{dt}\left(\frac{^Nd}{dt}\begin{Bmatrix} OP_1 \\ OP_2 \\ OP_3 \\ \vdots \\ OP_n \end{Bmatrix}\right)\right] \begin{matrix} \text{in boom} \\ \text{coordi-} \\ \text{nates} \end{matrix}$$

$$\cdots \cdots \cdots \cdots \cdots [9]$$

where N denotes the inertial frame, and $^Nd/dt$ denotes the time derivative in the N frame.

(b) Derivation of Individual Terms in $\ddot{U}$ Matrix Using Vector Analyses. Because the position vectors are independently differentiated, the procedure can be demonstrated by treating an arbitrary point P with position vector OP. In the differentiation process, OP must be rewritten in terms of known quantities, with the vectors fixed in the ship, crane, and boom. OP is expanded in terms of reference frame position vectors as shown in Fig. 3.

$$OP = OG + GL + LT + TP \quad \cdots \cdots \cdots [10]$$

where O, G, L, T, and P denote the vector end points, and the vectors are defined as follows:

OG = position vector of the ship relative to
     inertial space

GL = position vector of the crane relative to
     the ship's center of gravity

LT = position vector of the boom origin rela-
     tive to the crane

TP = position vector of the node P relative to
     the boom origin.

The reference frames for the above vectors are denoted by N, R, S, and B as shown in Fig. 1:

N = stationary inertial frame located at O

S = ship frame located at the ship's center of
    gravity, G

R = crane frame with its origin L on the crane's
    vertical axis of rotation

B = boom frame, with origin at boom's rotation
    point (the center point of the boom foot)
    and one axis along the boom centerline

The R, S, and B frames rotate, while N is fixed in space. The base vectors are defined in each frame as shown in Figs. 1 through 3, and are listed in Table 1. These base vector sets are interrelated by direction cosine matrices, C_{ij}, where the two subscripts define the frames (refer to Appendix).

When the expanded form of OP is differentiated, Eq. 10 provides

$$\frac{^N d}{dt}\left(\frac{^N d}{dt}\ OP\right) \;=\; \frac{^N d}{dt}\left[\frac{^N d}{dt}\ OG + \frac{^N d}{dt}\ GL\right.$$

$$\left. + \frac{^N d}{dt}\ LT + \frac{^N d}{dt}\ TP\right] \quad \ldots \ldots \ldots [11]$$

In vector differentiation, GL, LT, and TP are transformed using the following relationship

$$\frac{^I d}{dt}\ (\text{vector}) \;=\; \frac{^J d}{dt}\ (\text{vector}) \;+\; \omega^{JI}\ x\ (\text{vector})$$

$$\ldots \ldots \ldots \ldots \ldots \ldots \ldots [12]$$

where I and J define the reference frames, x denotes vector cross product, and ω is a rotational velocity vector (ω^{JI} is the rotational velocity of frame J relative to frame I, and $^I d/dt$ is differentiation in the I frame.) Refer to the Appendix for additional information regarding this transformation.

Using Eq. 12 to differentiate GL, LT, and TP

$$\frac{^N d}{dt}\ GL \;=\; \frac{^S d}{dt}\ GL \;+\; \omega^{SN}\ x\ GL \quad \ldots \ldots \ldots [13]$$

$$\frac{^N d}{dt}\ LT \;=\; \frac{^R d}{dt}\ LT \;+\; \omega^{RN}\ x\ LT \quad \ldots \ldots \ldots [14]$$

$$\frac{^N d}{dt}\ TP \;=\; \frac{^B d}{dt}\ TP \;+\; \omega^{BN}\ x\ TP \quad \ldots \ldots \ldots [15]$$

In order to simplify the terminology, a and V are used to represent acceleration and velocity. For arbitrary vector yz,

$$\frac{^{I}d}{dt}(yz) = V^{zI} \quad \ldots \ldots \ldots \ldots \ldots \ldots [16]$$

$$\frac{^{I}d}{dt}\left[\frac{^{I}d}{dt}(yz)\right] = \frac{^{I}d}{dt}V^{zI} = a^{zI} \quad \ldots \ldots \ldots [17]$$

where the first superscript on V and a defines the point at which the velocity or acceleration is occurring, and the second subscript denotes the reference frame, i.e., V^{zI} is the velocity of point z relative to the I frame.

Rewriting Eqs. 13, 14, and 15 in terms of the definitions in Eqs. 16 and 17 provides

$$V^{LN} = V^{LS} + \omega^{SN} \times GL \quad \ldots \ldots \ldots \ldots [18]$$

$$V^{TN} = V^{TR} + \omega^{RN} \times LT \quad \ldots \ldots \ldots \ldots [19]$$

$$V^{PN} = V^{PB} + \omega^{BN} \times TP \quad \ldots \ldots \ldots \ldots [20]$$

In Eqs. 18 and 19

$$V^{LS} = 0 \quad \text{and} \quad V^{TR} = 0 \quad \ldots \ldots \ldots [21]$$

because L is fixed in S (the crane support axis is not moving relative to the ship), and T is fixed in R (the crane boom support is fixed on the crane body).

Substituting Eqs. 18, 19, 20, and 21 into Eq. 11 and using the V and a notation provides

$$a^{PN} = \frac{^{N}d}{dt}\left[V^{GN} + V^{PB} + \omega^{SN} \times GL \right.$$

$$\left. + \omega^{RN} \times LT + \omega^{BN} \times TP \right] \ldots \ldots \ldots [22]$$

The second differentiation is performed in the same manner as the first. All the terms except V^{GN} are transformed as they are differentiated using Eq. 12.

The angular acceleration vector α is used in the final series of differentiations to denote the time derivative of the angular velocity vector,

$$\alpha^{JI} = \frac{^{I}d}{dt}\omega^{JI} \ldots \ldots \ldots \ldots \ldots \ldots [23]$$

where I and J are arbitrary reference frames. Differentiating the first term in Eq. 22 yields

$$\frac{^{N}d\ V^{GN}}{dt} = a^{GN} \ldots \ldots \ldots \ldots \ldots \ldots [24]$$

Differentiating the second term in Eq. 22 using Eq. 12 yields

$$\frac{^{N}d\ V^{PB}}{dt} = \frac{^{B}d\ V^{PB}}{dt} + \omega^{BN} \times V^{PB} \ldots \ldots \ldots [25]$$

where $^{B}d\ V^{PB}/dt = a^{PB}$. The third term in Eq. 22 is differentiated by parts first to obtain

$$\frac{^{N}d}{dt}(\omega^{SN} \times GL) = \frac{^{N}d}{dt}\omega^{SN} \times GL + \omega^{SN} \times \frac{^{N}d\ GL}{dt}$$

$$\ldots \ldots \ldots \ldots \ldots \ldots [26]$$

Then substituting from Eqs. 13, 18, 21, and 23, Eq. 26 can be written as

$$\frac{^N d}{dt} (\omega^{SN} \times GL) = \alpha^{SN} \times GL + \omega^{SN} \times (\omega^{SN} \times GL)$$

$$\dots \dots \dots \dots \dots [27]$$

In a similar manner the fourth and fifth terms in Eq. 22 are differentiated to obtain

$$\frac{^N d}{dt} (\omega^{RN} \times LT) = \alpha^{RN} \times LT + \omega^{RN} \times (\omega^{RN} \times LT)$$

$$\dots \dots \dots \dots \dots [28]$$

$$\frac{^N d}{dt} (\omega^{BN} \times TP) = \alpha^{BN} \times TP + \omega^{BN} \times V^{PB}$$

$$+ \omega^{BN} \times (\omega^{BN} \times TP) \dots [29]$$

Substituting Eqs. 24, 25, 27, 28, and 29 into Eq. 22 yields

$$a^{PN} = a^{GN} + a^{PB} + 2\omega^{BN} \times V^{PB} + \alpha^{SN} \times GL$$

$$+ \omega^{SN} \times (\omega^{SN} \times GL) + \alpha^{RN} \times LT$$

$$+ \omega^{RN} \times (\omega^{RN} \times LT) + \alpha^{BN} \times TP$$

$$+ \omega^{BN} \times (\omega^{BN} \times TP) \dots \dots [30]$$

Eq. 30 defines the inertial acceleration of boom point P in terms of known quantities and the boom relative velocity and acceleration. The boom coordinate components of a^{PN} are terms in the $\ddot{U}$ matrix. The other terms in $\ddot{U}$ are obtained by substituting the position vectors (TP_i) for points P_i into Eq. 30.

(c) <u>Individual Terms in the $\ddot{Q}$ Matrix</u>. The $\ddot{Q}$ matrix terms are determined directly from Eq. 30, thereby making the assembly of $\ddot{U}$ unnecessary. Lower case letters $\ddot{x}$, $\ddot{x}$, $\ddot{q}$, u, and $\ddot{u}$ are used to denote the vectors forming the $\dot{X}$, $\ddot{X}$, $\ddot{Q}$, U, and $\ddot{U}$ matrices. Subscripts identify the node point. The quantities in Eq. 30 are related to $\ddot{U}$ and $\ddot{X}$ as follows:

From Eqs. 8 and 17, a^{PN} for node i = $\ddot{u}_i$ and by definition

$$a^{P_iB} = \ddot{x}_i \quad \text{and} \quad V^{P_iB} = \dot{x}_i \quad \ldots \ldots [31]$$

The relationship between $\ddot{q}$, $\ddot{u}$, and $\ddot{x}$ is obtained from Eq. 7

$$\ddot{q}_i = \ddot{u}_i - \ddot{x}_i \quad \ldots \ldots \ldots \ldots \ldots \ldots [32]$$

Rewriting Eq. 30 in terms of $\dot{x}$, $\ddot{x}$, u, and $\ddot{u}$ for an arbitrary point i (substituting Eq. 31 into Eq. 30) and then substituting the revised Eq. 30 into Eq. 32 yields:

$$\ddot{q}_i = a^{GN} + 2\omega^{BN} \times \dot{x}_i + \alpha^{SN} \times GL$$

$$+ \omega^{SN} \times (\omega^{SN} \times GL) + \alpha^{RN} \times LT$$

$$+ \omega^{RN} \times (\omega^{RN} \times LT) + \alpha^{BN} \times TP_i$$

$$+ \omega^{BN} \times (\omega^{BN} \times TP_i) \quad \ldots \ldots \ldots \ldots [33]$$

The terms containing length vectors (LT, GL, and TP_i) predominate in Eq. 33. The time derivative of the boom deformation ($\dot{x}_i$) measured relative to the boom axis is very small, making the components of ($\omega^{BN} \times \dot{x}_i$) second-order terms. Neglecting ($\omega^{BN} \times \dot{x}_i$), the vectors in Eq. 33 can be separated into two groups. One group contains the crane support acceleration and is independent of the node point. The vectors in this

group are identical for each node. The other group contains the tangential and centripetal acceleration of the boom and is a function of the node coordinate (TP_i, measured relative to the boom reference frame). The vector matrix equation for $\ddot{q}$ in terms of these groups can be written

$$\ddot{q}_i = e\ b + f\ TP_{ib} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad [34]$$

where e and f are scalar components multiplying vectors in the boom reference frame (b denotes the unit base vectors in B, and TP_{ib} denotes the vector coordinates of node i directed along the base vectors b.)

The vectors in Eq. 33 are written in terms of the boom axis as shown in Eq. 34, because eventually they must be incorporated into the equation of motion. Values for e and f can be obtained from the following vector dot product

$$e = \left[a^{GN} + \alpha^{SN} \times GL + \omega^{SN} \times (\omega^{SN} \times GL) \right.$$

$$\left. + \alpha^{RN} \times LT + \omega^{RN} \times (\omega^{RN} \times LT) \right] \cdot b \quad . \quad . \quad [35a]$$

$$f = \frac{\left[\alpha^{BN} \times Tp_i + \omega^{BN} \times (\omega^{BN} \times Tp_i) \right] \cdot b}{Tp_i \cdot b} \quad . \quad . \quad . \quad [35b]$$

However, it is usually easier to perform the vector operations (Eq. 35) in the ship's coordinate system and then convert to the b basis using direction cosine matrices. This procedure will be demonstrated in the next section. In all, twelve functions need to be computed, three for e and a 3 x 3 matrix of functions for f. The vector operations can be coded, and the calculations performed in a separate program. The resulting functions (e and f) are then input to the structural analysis program along with the description of the structure. The modifications to the structural analysis program relate to the appropriate inclusion of e

and f in the node equations of motion. (The node coordinates TP_i are automatically included as part of the structural input.) The positioning of e and f can be shown using the expanded form for $\ddot{Q}$. When the $\ddot{q}_i$ terms for each node from Eq. 34 are combined, the $\ddot{Q}$ matrix is generated:

$$\ddot{Q} = \begin{Bmatrix} e \\ e \\ e \\ \vdots \\ e \end{Bmatrix} + \begin{bmatrix} f & & & \\ & f & & \\ & & f & \\ & & & f \end{bmatrix} \begin{Bmatrix} TP_1 \\ TP_2 \\ TP_3 \\ \vdots \\ TP_n \end{Bmatrix} \quad \dots \dots \dots [36]$$

The base vectors b in Eq. 34 are not included because $\ddot{Q}$ is not a vector. However, $\ddot{Q}$ must always be written in terms of boom coordinate quantities, because it is used in Eq. 6.

The inertial loads are obtained by multiplying $\ddot{Q}$ by M. Then, as shown in Eq. 6, the matrix product $(-M\ddot{Q})$ is positioned on the right side of the equation of motion. This matrix in effect, applies inertia forces at each boom node. The relative displacements at each node (X_i) are obtained by solving Eq. 6. Finally, using these displacements, the stresses in the boom are computed from element strain displacement relationships.

Computation of the e and f Matrices. The e and f matrices are calculated using the vector operations shown in Eq. 33. To perform the cross product, the vectors are written in terms of a common base vector set (refer to Table 1 for list of base vectors). Then, because the equation of motion is in boom-fixed coordinates, all vector quantities are transformed to the boom coordinate system using direction cosine matrices (see Appendix).

In order to compute e and f, the following quantities are required:

1. Position vectors shown in Figure 2.

$$GL = L_x s_x + L_y s_y + L_z s_z \quad \ldots \ldots \quad [37]$$

$$LT = T_x r_x + T_y r_y \quad \ldots \ldots \ldots \ldots \quad [38]$$

$$TP_i = P_{xi} b_x + P_{yi} b_y + P_{zi} b_z \quad \ldots \ldots \quad [39]$$

where s, r, and b represent the ship, crane, and boom base vectors, and the L and T are measured dimensions locating the boom on the ship. P_{xi}, P_{yi}, and P_{zi} are the coordinates of node i.

2. Rotational velocity and rotational acceleration of the ship relative to inertial space.

$$\omega^{SN} = \omega_x s_x + \omega_y s_y + \omega_z s_z \quad \ldots \ldots \quad [40]$$

$$\alpha^{SN} = \alpha_x s_x + \alpha_y s_y + \alpha_z s_z \quad \ldots \ldots \quad [41]$$

3. Translational acceleration of the ship relative to inertial space.

$$a^{GN} = a_x s_x + a_y s_y + a_z s_z \quad \ldots \ldots \quad [42]$$

4. Rotational velocity and rotational acceleration of the crane cab relative to the ship.

$$\omega^{RS} = \dot{\theta} r_y = \dot{\theta} s_y \quad \ldots \ldots \ldots \ldots \quad [43]$$

$$\alpha^{RS} = \ddot{\theta} r_y = \ddot{\theta} s_y \quad \ldots \ldots \ldots \ldots \quad [44]$$

where $\dot{\theta}$ and $\ddot{\theta}$ are the magnitudes of swing angular velocity and acceleration.

5. The rotational velocity and rotational acceleration of the boom relative to the cab.

$$\omega^{BR} = \dot{\beta}b_z = \dot{\beta}r_z = \dot{\beta} \sin \theta \ s_x + \dot{\beta} \cos \theta \ s_z \quad . \ .[45]$$

$$\alpha^{BR} = \ddot{\beta}b_z = \ddot{\beta}r_z = \ddot{\beta} \sin \theta \ s_x + \ddot{\beta} \cos \theta \ s_z \quad . \ .[46]$$

where $\dot{\beta}$ and $\ddot{\beta}$ represent the magnitudes of boom angular velocity and acceleration.

The vectors GL, LT, TP_i, ω^{SN}, α^{SN}, and a^{GN} used in the calculation of e and f (Eq. 35) are obtained directly from Eqs. 37, 38, 39, 40, 41, and 42, respectively. The remaining vectors, α^{RN}, α^{BN}, ω^{RN}, and ω^{BN}, are functions of the vectors defined in Eqs. 40 through 46. For example, using the angular velocity vector chain rule (refer to the Appendix), ω^{RN} can be written

$$\omega^{RN} = \omega^{SN} + \omega^{RS} \quad . . . .[47]$$

and ω^{BN} as

$$\omega^{BN} = \omega^{SN} + \omega^{RS} + \omega^{BR} \quad . . . .[48]$$

The angular velocity vectors α^{RN} and α^{BN} are obtained by differentiating the expanded velocity vectors in Eqs. 47 and 48. The equation for α^{RN} is

$$\alpha^{RN} = \frac{^N d}{dt} \omega^{RN} = \frac{^N d}{dt} \left(\omega^{SN} + \omega^{RS} \right) \quad . . . . . .[49]$$

and for α^{BN} it is

$$\alpha^{BN} = \frac{{}^N d}{dt}\left(\omega^{SN} + \omega^{RS} + \omega^{BR}\right) \quad \ldots \ldots \ldots [50]$$

Using Eq. 12 to differentiate, Eq. 49 becomes

$$\alpha^{RN} = \alpha^{SN} + \alpha^{RS} + \omega^{SN} \times \omega^{RS} \quad \ldots \ldots \ldots [51]$$

and Eq. 50 is written

$$\alpha^{BN} = \alpha^{SN} + \alpha^{RS} + \alpha^{BR} + \omega^{SN} \times \omega^{RS}$$

$$+ \left(\omega^{SN} + \omega^{RS}\right) \times \omega^{BR} \quad \ldots \ldots \ldots [52]$$

These angular acceleration vectors can be expressed in the s basis. Using Eqs. 40, 41, 43, and 44, Eq. 51 can be written

$$\alpha^{RN} = (\alpha_x - \omega_z \dot{\theta})s_x + (\alpha_y + \ddot{\theta})s_y$$

$$+ (\alpha_z + \omega_x \dot{\theta})s_z \quad \ldots \ldots \ldots \ldots [53]$$

and using Eqs. 40, 41, 43, 44, 45, and 46, Eq. 52 can be written

$$\alpha^{BN} = [\alpha_x - \omega_z \dot{\theta} + \ddot{\beta} \sin \theta$$

$$+ (\dot{\theta} + \omega_y)\dot{\beta} \cos \theta]s_x + [\alpha_y + \ddot{\theta}$$

$$+ \omega_z \dot{\beta} \sin \theta - \omega_y \dot{\beta} \cos \theta]s_y$$

$$+ [\alpha_z + \omega_x \dot{\theta} + \ddot{\beta} \cos \theta$$

$$- (\omega_y + \dot{\theta})\dot{\beta} \sin \theta]s_z. \quad \ldots \ldots \ldots [54]$$

All the vectors required in the calculation of e and f are defined in Eqs. 37 through 54. To compute the e column matrix, the vector operations and additions are done in the s basis and the results transformed to the b basis using C_{SB} from the Appendix. The terms of f are computed by transforming α^{BN} and ω^{BN} to the b basis and performing the vector cross product in the b frame. The terms of e and f would be computed using matrix multiplication on the digital computer so that the rather cumbersome equations for the e and f terms are never required. However, for checking purposes, the equations for the terms can be obtained from the authors.

SUMMARY

A procedure is presented for computing the dynamic loads produced on a crane boom by ship and boom motion (pendulation of the load is not included). With this procedure, any combination of rotational and translational motion can be simulated. Although the procedure requires a minor modification to the structural analysis program, it greatly extends the possible applications for the program.

The equations of motion are derived in their simplest form, minimizing computation and program modifications. Only twelve time functions are required to generate the translational and rotational inertial loads. Although the equations are linear, nonlinear large angle rotations are included to maintain accuracy.

Once the structural analysis program is modified, the dynamic stresses in the boom that are induced by the shipboard environment can be easily and efficiently computed.

NOMENCLATURE

a	acceleration
B	boom reference frame
b	boom unit vectors
C	direction cosine matrix
e	inertial load functions, independent of nodal coordinates
$\bar{e}$	arbitrary unit vectors
F	generalized loads matrix
f	inertial load functions multiplying nodal coordinates
G	point defined by ship's center of gravity
I, J	arbitrary reference frames
K	structural stiffness matrix
L	point on crane cab rotation axis
ℓ	vector length
M	lumped mass matrix
N	inertial reference frame
O	origin of inertial frame
P	node point on boom
Q, $\ddot{Q}$	displacement and acceleration matrices
q, $\ddot{q}$	terms in the Q and $\ddot{Q}$ matrices
R	crane cab reference frame
r	crane cab unit vectors
S	ship reference frame
s	ship unit vectors
T	point on boom support axis (origin of boom coordinate system)
U, $\ddot{U}$	nodal displacement and acceleration matrices relative to inertial space
u, $\ddot{u}$	terms in U and $\ddot{U}$ matrices
V	velocity vector
$X, \dot{X}, \ddot{X}$	nodal displacement, velocity, and acceleration matrices relative to the boom axis
$\dot{x}, \ddot{x}$	terms in the X and $\ddot{X}$ matrices
yz	arbitrary vector
z	arbitrary point
α	angular acceleration
ω	angular velocity
θ, β	boom angles refer to Figure 2

d/dt and ($\cdot$) denote differentiation with respect to time.

REFERENCES

1. Ward, C. C., and R. B. Thompson. "The Development of a Detailed Finite Element Brain Model." Proc. 19th Stapp Car Crash Conference, 1975.

2. Likins, P. Elements of Engineering Mechanics. McGraw-Hill Book Company, 1973.

APPENDIX

Direction Cosine Matrices. The base vectors are interrelated by direction cosine matrices, C_{ij}, where the subscripts define the reference frames (Table 1). For example:

$$\begin{Bmatrix} S_x \\ S_y \\ S_z \end{Bmatrix} = \begin{bmatrix} C_{SB} \end{bmatrix} \begin{Bmatrix} b_x \\ b_y \\ b_z \end{Bmatrix} \quad \dots \dots \dots \dots \dots \dots [A\text{-}1]$$

where

$$C_{SB} = \begin{bmatrix} \cos\theta\,\cos\beta & -\cos\theta\,\sin\beta & \sin\theta \\ \sin\beta & \cos\beta & 0 \\ -\sin\theta\,\cos\beta & \sin\beta\,\sin\theta & \cos\theta \end{bmatrix} \dots [A\text{-}2]$$

Chain Rule for Angular Velocity Vectors. Angular velocity vectors can be expressed using intermediate reference frames (Ref. 2),

$$\omega^{IJ} = \omega^{IK} + \omega^{KJ} \quad \dots \dots \dots \dots \dots \dots [A\text{-}3]$$

where K is the intermediate reference frame. For the boom,

$$\omega^{BN} = \omega^{BR} + \omega^{RS} + \omega^{SN} \quad \ldots \ldots \ldots \quad [A\text{-}4]$$

<u>Vector Differentiation/Transformation</u>. The following equation is used to differentiate and transform vectors.

$$\frac{^I d}{dt}(yz) = \frac{^J d(yz)}{dt} + \omega^{JI} \times yz \ldots \ldots \quad [A\text{-}5]$$

The proof follows:

Let the arbitrary vector yz be written in terms of its magnitude ℓ and an appropriate unit vector e so that

$$yz = \ell\,\overline{e} \quad \ldots \ldots \ldots \ldots \ldots \ldots \quad [A\text{-}6]$$

Application of the product rule of differentiation yields

$$\frac{^I d(yz)}{dt} = \dot{\ell}\,\overline{e} + \ell\,\frac{^I d\,\overline{e}}{dt} \ldots \ldots \ldots \quad [A\text{-}7]$$

$$\frac{^J d(yz)}{dt} = \dot{\ell}\,\overline{e} + \ell\,\frac{^J d\,\overline{e}}{dt} \ldots \ldots \ldots \quad [A\text{-}8]$$

Let C be a reference frame in which $\overline{e}$ is fixed. Then from the definition of angular velocity,

$$\frac{^I d\,\overline{e}}{dt} = \omega^{CI} \times \overline{e} \quad \ldots \ldots \ldots \ldots \quad [A\text{-}9]$$

and

$$\frac{^J d\,\overline{e}}{dt} = \omega^{CJ} \times \overline{e} \quad \ldots \ldots \ldots \ldots \quad [A\text{-}10]$$

Substituting Eqs. A-9 and A-10 into the difference of Eqs. A-7 and A-8 yields

$$\frac{^I d\ yz}{dt} - \frac{^J d\ yz}{dt} = \ell \left[\omega^{CI} - \omega^{CJ} \right] \times \bar{e} \quad . . . [\text{A-11}]$$

Using Eq. A-6' and the relationship $-\omega^{CJ} = \omega^{JC}$, Eq. A-11 can be simplified to

$$\frac{^I d\ yz}{dt} = \frac{^J d\ yz}{dt} + \left[\omega^{CI} + \omega^{JC} \right] \times yz \quad . . . [\text{A-12}]$$

Finally, the chain rule for angular velocities (Eq. A-3) permits the substitution of ω^{JI} in the brackets, which proves Eq. A-5.

Table 1. Reference Frame Definition

Name	Symbol	Base Vectors	Origin Point	Origin Location	Angles Between Frames
Inertial	N	n_x, n_y, n_z	O	Unspecified	–
Ship	S	s_x, s_y, s_z	G	Ship CG	θs_y
Crane	R	r_x, r_y, r_z	L	Vertical rotation axis of cab	βr_z
Boom	B	b_x, b_y, b_z	T	Crane boom center of rotation	–
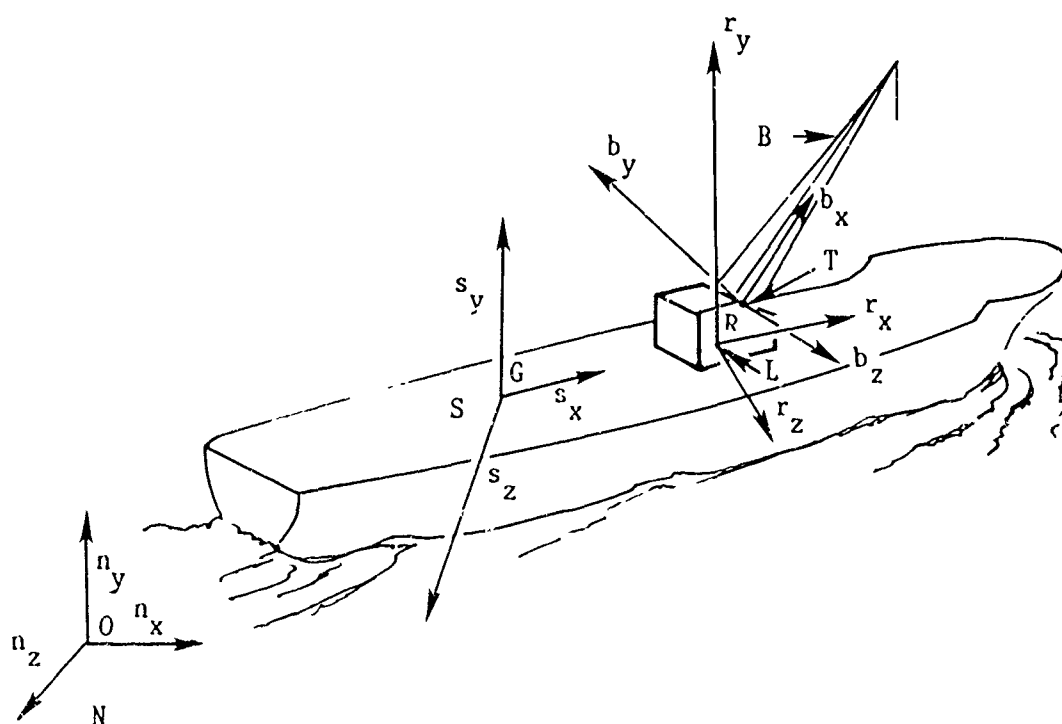
Figure 1. Coordinate system.
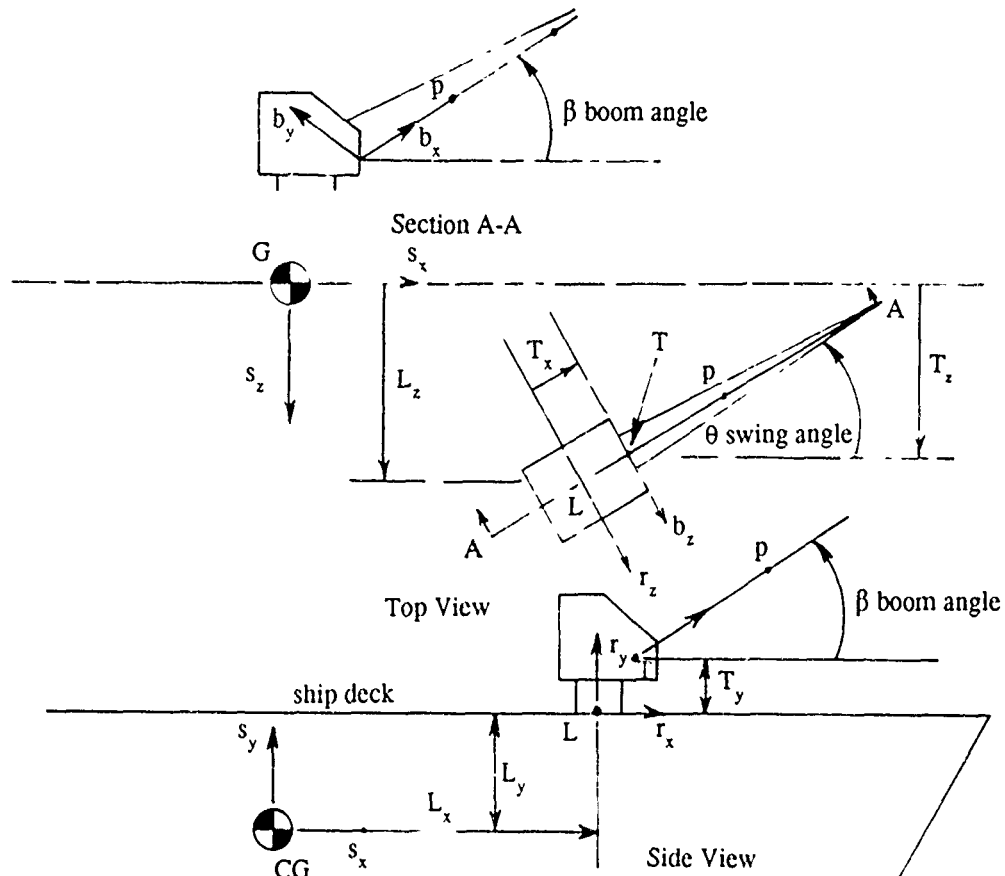
Figure 2. Crane orientation.
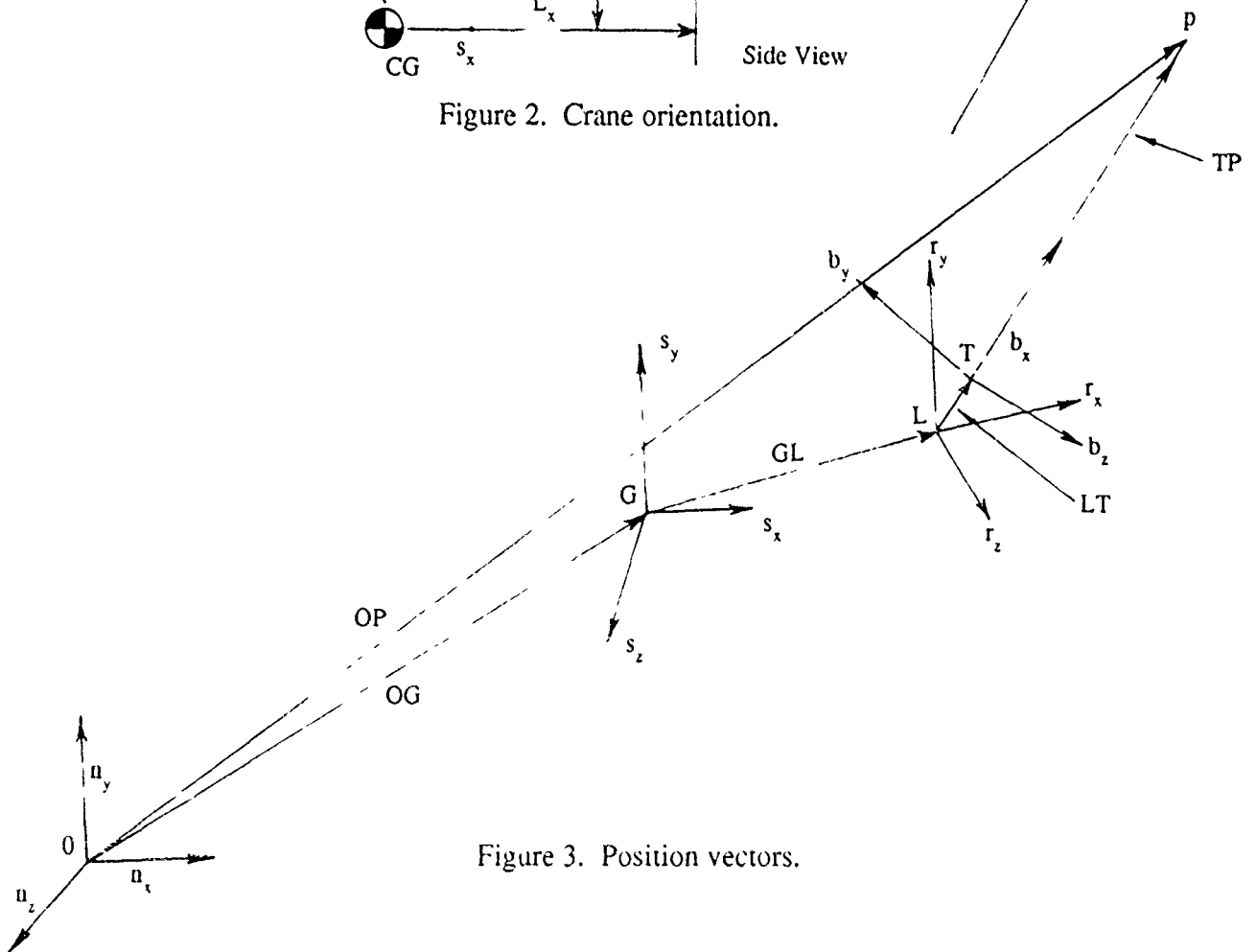
Figure 3. Position vectors.

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